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ECOLOGICAL STUDIES OF THE BEET LEAF HOPPER

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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BY WALTER CARTER

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INTRODUCTION

A tiny cicadellid, *Eutettix tenellus* Baker (the beet leaf hopper),[2] is responsible for a serious disease (commonly called curly top) of sugar beets and other truck crops in the western part of the United States, and the problem has become of increasing importance to the sugar industry within recent years. Sugar factories have been dismantled and moved to other places, only to be dismantled and moved again when it was found that the areas moved into were subject to invasions of the insect. Many factories in the intermountain region have operated on an intermittent basis or not at all. Since the three factories in the central part of the Snake River Valley in southern Idaho have been built they have never run more than 50 per cent of their total capacity.

[1] Acknowledgments: To J. E. Graf, in charge of the Division of Truck-Crop Insects of the Bureau of Entomology, of which this project is a part, the writer's especial thanks are due; his constant encouragement and suggestions, together with a never-failing administrative support, have been invaluable. R. N. Chapman, of the University of Minnesota, has served in the capacity of collaborator of the Bureau of Entomology in connection with this study and his assistance is gratefully acknowledged. Specific mention of all of those who from time to time have lent assistance would involve too much space, but especial mention should be made of Eubanks Carsner, Bureau of Plant Industry, and the following members of the project staff: Clement H. Griffith, Van E. Romney, Arthur Goodrich, E. W. Davis, H. E. Wallace, and Rowland W. Haegele (of the Idaho experiment station). The officers of the Amalgamated Sugar Co. have given assistance of the most valuable kind; in particular the cooperation of Messrs. Swendsen, Cottrell, and Hagar of that company has been an important factor in the development of the study. Acknowledgments are also due to E. D. Ball, whose stimulating memorandums on the subject of the study were valuable and informative.

[2] This insect is also known locally as the "white fly."

In Table 1 are listed data from the records of the company owning these mills covering the period of operation of the factory at Twin Falls. The table is instructive, since it illustrates the necessity for the study reported in this bulletin.

TABLE 1.—*Acreage record for the beet-sugar factory at Twin Falls, Idaho, 1916–1926*

Year	Area planted	Area harvested	Area abandoned on account of Eutettix tenellus	Yield per acre	Year	Area planted	Area harvested	Area abandoned on account of Eutettix tenellus	Yield per acre
	Acres	*Acres*	*Acres*	*Tons*		*Acres*	*Acres*	*Acres*	*Tons*
1916	5,764	5,321	(1)	12.13	1922	2,434	2,267	0	13.52
1917	6,540	5,860	(1)	10.91	1923	4,574	4,568	0	14.19
1918	3,583	3,254	(1)	11.88	1924	7,519	3,113	4,406	5.50
1919	6,107	4,695	1,150	7.65	1925	3,241	3,003	60	14.26
1920	5,760	4,722	0	11.58	1926	2,492	282	2,210	6.01
1921	7,586	6,066	1,520	7.97					

[1] Leaf hopper in territory but no data on actual loss available.

From Table 1 it is seen that from 1919, the first year when serious losses occurred in the Twin Falls factory district, until 1925 there has been a reduced acreage following every outbreak. This acreage has then increased to a high point only to meet with reverses due to another outbreak. The outbreaks have coincided with the years of greatest acreage.[3] The depressing effect on the industry caused by this intermittency has been rendered more pronounced by the lack of advance information as to which years were to be years of outbreak.

In 1917 Ball (*1, p. 36*) [4] made the following statement:

> Any information by which the probable occurrence of these periodic outbreaks could be foretold would, therefore, be worth millions of dollars to this industry. This information can only be obtained by long and careful study of the habits and reproductive power of the insect on its native food plants and in its natural breeding range.

It was with this objective in mind that the present study was started in the spring of 1925. Headquarters were first established at Toppenish, Wash., but were moved in August of that year to Twin Falls, Idaho, where the sugar industry was still attempting to maintain itself. The situation there, as reference to Table 1 will show, is a most serious one, serious damage having occurred in four of the nine years since 1919. All three factories (at Twin Falls, Burley, and Paul) lie within a permanent breeding ground of *Eutettix tenellus*, and therefore an excellent opportunity was presented for this study.[5]

Primarily, the problem was to endeavor to establish a basis for predicting outbreaks, by the use of ecological methods and technic. It is realized that predicting in an area with the past record of the southern Idaho district is at best a palliative and can not be considered a permanent solution. It will, however, if successful, do more to maintain the industry until a permanent solution can be found than any other method which might be devised.

[3] The reduced acreage in 1926, while probably affected by crop competition, is an indication that farmers recognized the danger of damage following the extremely mild winter of 1925–26—a recognition that was fully supported by subsequent events that season.

[4] Italic numbers in parentheses refer to "Literature cited," p. 113.

[5] For purely physical reasons the detailed study was limited to a comparatively small area which appeared to represent a suitable unit for study.

THE METHOD OF APPROACH TO THE PROBLEM

The problem involves the study of the ecology of the insect, both in its native desert environment and in the beet fields. The questions to be answered in the course of the investigation involve the relationships of the insect to its host plants and the relationships of the insect and the host plants to the desert, with its extreme physical factors of moisture and temperature. The possible explanation for the migration of the insect from the desert to the beet fields involves a study of all the factors of both environments which make for large Eutettix populations and their successful establishment in the beet fields. The fact that the insect transmits a virus which causes a disease of the beets necessitates the consideration of this disease, the insect's transmission of it, and the beet's susceptibility to it.

The first step was to study the environment of the insect. Such a study had several phases. One was a consideration of the physical factors. Thermographs were set up at intervals through the area and a detailed observation station was established at Twin Falls. At the latter place hygrothermograph records, evaporation data, and, by means of an electric-resistance thermometer outfit, temperature records through the vertical range of the local environment were taken. Data on wind movement were obtained by means of a recording cup anemometer. In cooperation with the United States Weather Bureau, records of solar radiation were obtained by means of a Kimball pyrheliometer attached to an Engelhardt recorder.

The place chosen for this observation station was typical of the insect's breeding grounds, so the data obtained represent a fair record of the physical factors of the average environment of the insect.

Laboratory studies on the effect of the physical factors on the insect were run concurrently with the study of the external environment. Those dealing with the effect of low temperatures were checked up by means of extensive field studies on hibernation and winter survival. The field cages used in these experiments were located at the observation station where the temperature and other records were taken.

Another phase of the investigation was a study of the insect's host plants from the standpoint of both plant and insect. Moot questions were: Which species were favored hosts? What was their comparative longevity? Was there a succession of host plants through the season? The concentration of the cell sap of the host plants was recorded as a possible measuring stick whereby both the plant's development and the insect's reaction could be followed. Careful notes on the development of the plants throughout the season were also taken. Quantitative collections of the insect populations were made throughout the season. These were made with an American landing net, each collection consisting of 50 or 100 sweeps of the net. All the insects were sorted out, counted, and recorded. In this way a numerical measure of the populations of *Euttettix tenellus* on each host plant was obtained.

Another phase, closely related to the last mentioned, was a study of the entire insect community to which *E. tenellus* belongs. This was accomplished by counting and recording all the insects obtained in the quantitative collections.

Finally, with all the foregoing data at hand, the climate of the region was studied and relationships between outbreaks of the insect and weather were worked out. This led to two important economic applications of the data, one to prediction of outbreaks, and the other to the determination of the probable economic distribution of the insect. These in turn led to a consideration of the environmental complex, its importance and usefulness as a working basis for entomologists.

GENERAL OUTLINE OF THE LIFE HISTORY OF THE INSECT IN SOUTHERN IDAHO

Eutettix tenellus hibernates as an adult and during the winter develops its eggs. Its hibernation has been described as "incomplete hibernation" by Severin (*26*). The fact that it does not develop its eggs during the late fall, even though the temperatures are higher than prevail during the warmest days of the winter, suggests that, hibernation may consist of a rest period without dormancy, and that, in the case of *E. tenellus*, this rest period is broken up sometime during midwinter. The preoviposition period of overwintering *E. tenellus* in the field can not be explained on the basis of ordinary temperature summation, as reference to the detailed temperature experiments will show. It has nevertheless been proved during the seasons of 1926, 1927, and 1928 that the overwintering females have developed their eggs by the end of February or the middle of March. Oviposition starts on the desert host plants much earlier than previous studies would indicate. Nymphs were found in numbers the first week of April, 1926, and fresh adults April 17. In 1927 nymphs were common at Glenns Ferry on May 6; these emerged as males in the laboratory on May 17. A third-instar nymph was taken close to Twin Falls on May 19, indicating that the brood was well under way at that place on that date. Nymphs were found at Twin Falls on May 2, 1928.

The previous work (*1*, *32*) indicating that the insect is single-brooded is not substantiated by the work in the area here reported. The difficulty probably lies in the fact that the beet field was the scene of life-history observations and the possibility that a brood may have occurred on the desert before the flight was overlooked.

An excellent criterion for the first appearance of the first generation is to be found in the fact, established by experiment and observation, that the males rarely overwinter. The sudden appearance of males after nymphs have been found is a clear indication that the first generation is appearing. Since the males appear first, the appearance of fresh females is an indication that the adults of the new generation have been emerging for some time. The question of color is involved here. As a general rule the color of overwintering females is dark. This color varies very much between individuals, but there is no difficulty in the spring in distinguishing between the overwintering females and the new generation. The new-generation adult has a distinctive cream-green color which effectively distinguishes it from its parents.

In 1926, when the spring was most unusually dry and warm, the desert host plants were dried out by the first week in May and a terrific infestation in the beet fields followed. Observations in the

desert breeding grounds prior to this indicated without question that the first brood was well advanced. Counts of the insects collected in the beet fields the first week in May showed a normal percentage of males. Most of the insects, male and female, were of the color typical of the new brood, but some dark forms were noticed. This means that under such conditions oviposition for the first brood might be practically completed in the desert breeding grounds but finished in the beet fields. The small and mostly noneconomic populations of *Eutettix tenellus* encountered in beet fields in 1927 were all light colored. As a matter of fact, at that time, dark overwintering forms could not be found on the desert breeding grounds except in very rare instances. Observations in this area (which might, of course, not hold for other areas) indicate that the first generation is rapidly developed on the desert and oviposition by the overwintering females is completed before the spring season is ended.

The life history of the insect in a beet field is conditioned by factors which are not present in the insect's desert environment, so the number of generations may be quite different in the two environments. Data are presented later to show that the insect's optimum environment is to be found in the desert on its wild host plants and that this optimum condition is only approached in a beet field if the stand is poor and growth retarded, as is the case if the beets are severely affected by curly top. Quantitative data from the field collections indicate that on the native hosts there are three generations of the insect in this area, the size of the third generation being dependent on fall weather conditions. (See Haegele (*19*).) On beets there are two generations, the second and third of the insect's seasonal development.

THE DESERT ENVIRONMENT OF EUTETTIX TENELLUS

PHYSICAL FACTORS OF THE ENVIRONMENT

MEASUREMENT OF THE FACTORS

The principal technical problem confronting the ecologist is the description of environments in terms of precision. This is less a problem in connection with physical factors than it is with biotic factors. The importance of physical factors has been the subject of much investigation, which is reviewed at length by Chapman (*8*). The factors measured in this study are solar radiation, humidity, temperature, evaporation, wind movement, and precipitation. Soil moisture, presenting a summary of factors, is used in connection with desert observation stations and is listed in Tables 19 and 20 and in Table 40. Measurements of temperature include standard shade (Weather Bureau shelter), soil-surface temperatures, and a series of temperatures through the vertical range of the environment, which were taken at the surface and 6 and 27 inches above the surface. Humidity records are limited to the hygrothermograph records under standard-shade conditions, except that a few hygrothermograph records were obtained from several situations for short periods to illustrate particular points. Atmometer records of evaporation are available for the three seasons 1926, 1927, and 1928. These records cover only the period from spring to fall, or, perhaps more accurately, the frost-free period of the year.

The data are grouped for the most part according to season, since in that way their special significance is more forcibly brought out. The winter conditions are considered with respect to hibernation, and spring conditions with respect to the development of the first

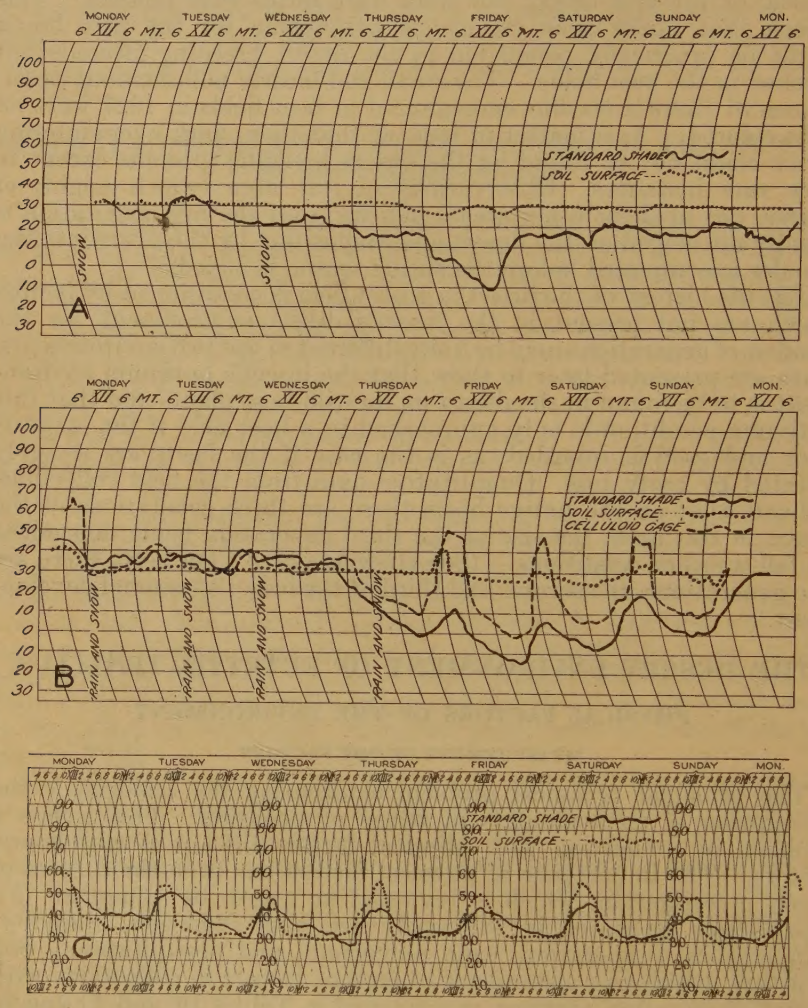


FIGURE 1.—Comparison of temperatures in different positions, Twin Falls, Idaho: A, Temperatures at soil surface and in standard shade, week ended January 24, 1926; rain and snow fell on December 2, 3, 6, 7, 8, 9, 11, and 12, and snow fell on December 13, 20, and 22; B, temperatures at soil surface, in standard shade, and in celluloid hibernation cages, week ended January 24, 1927; rain and snow fell on January 17, 18, 19, and 20; C, temperatures at soil surface and in standard shade, week ended February 28, 1927

brood and migration, while summer and fall conditions are considered in connection with the development of the desert populations. The data are presented here with brief discussion, further elaboration being left to the sections of this bulletin dealing with specific divisions of the problem.

The data of figure 1, A and B, illustrate important intraenvironmental differences in winter temperatures. The solid black line show-

ing air temperatures in standard shade is to be compared with the dotted line showing temperatures at the soil surfaces. From these it is seen that when snow fell prior to cold waves the temperatures at the surface of the soil were practically constant at around freezing point during the succeeding cold weather when air temperatures fell considerably below zero. These data are discussed further in connection with hibernation studies.

Figure 1, C, illustrates a condition converse to that shown in A and B. It will be noted that there are midday peaks on both curves and that the soil-surface temperatures reached points favorable to activity of *Eutettix tenellus* while air temperatures remained below the favorable point. It is through increments of such favor-

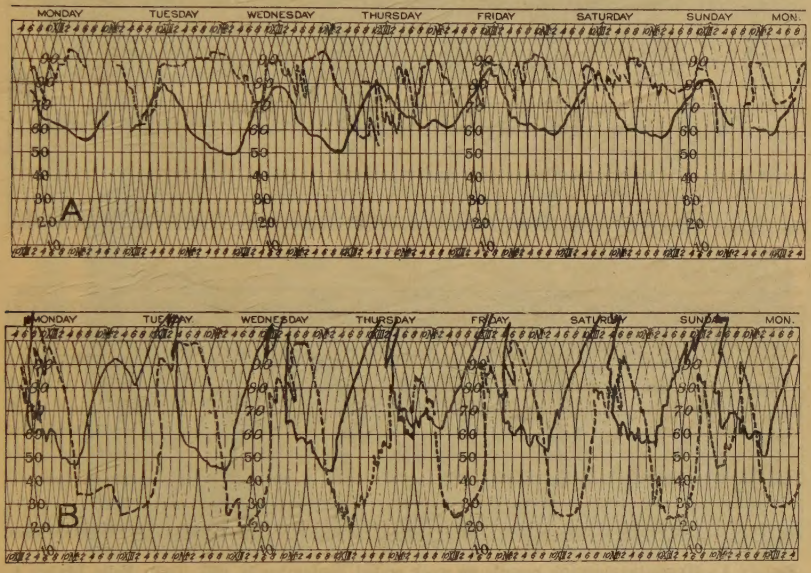


FIGURE 2.—Hygrothermograph records for week ended August 22, 1927, Twin Falls, Idaho. Relative humidity shown by dotted line, temperature shown by solid line: A, Hygrothermograph record from a beet field; B, hygrothermograph record from a stand of Russian thistle (*S. pestifer*) close to the beet field

able temperatures that the insect is enabled to develop its eggs during the winter months.

Figure 2 represents data taken for the purpose of illustrating differences between sugar beet and Russian thistle (*Salsola pestifer*) with respect to the environments offered to *E. tenellus*. The humidity of the beet field was consistently high, while the humidities in the stand of Russian thistle fluctuated widely. The data also show differences with respect to temperature. In both cases the instruments were on the ground. The minimum temperatures do not differ much but the maximum temperatures show wide variation. In the thistle stand these maxima exceeded 100° F. every day while in the beet field the maxima exceeded 80° only slightly on three days. The beets were large and completely shaded the ground. The thistle stand shown in Plate 1, A, was typical of those areas breeding high populations of *E. tenellus*.

The hygrothermograph record presented in Figure 3, A, was taken in part of a beet field where the beets were in poor condition, and the record in Figure 3, B, was taken in another part of the same field where the beets were thrifty. (Pl. 1, B.) By comparing these two records it is seen that poorly growing beets having little leaf development provide more favorable temperature conditions than do the more rankly growing beets. These thin spots in the field were the only places where the activity of the insect was evident. By comparing Figures 2, B, and 3, A, it is seen that the environment offered by such beets approaches that of a stand of sparsely growing *Salsola pestifer*. Poor stands, very young beets, or beets suffering severely from curly

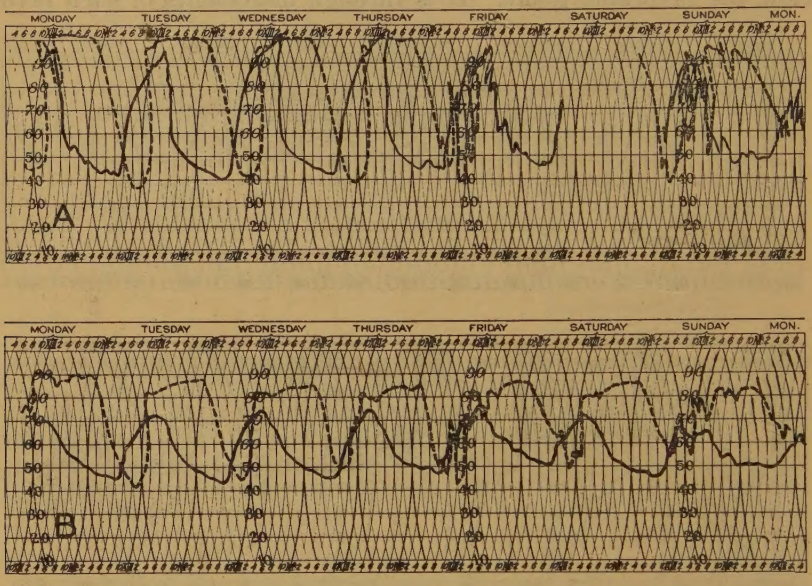


FIGURE 3.—Hygrothermograph records for week ended September 24, 1927, Twin Falls, Idaho: A, Hygrothermograph records from a place in a beet field where cultural conditions were poor and beets were unthrifty; B, hygrothermograph record from another place in the same beet field where cultural conditions were excellent and beets were thrifty

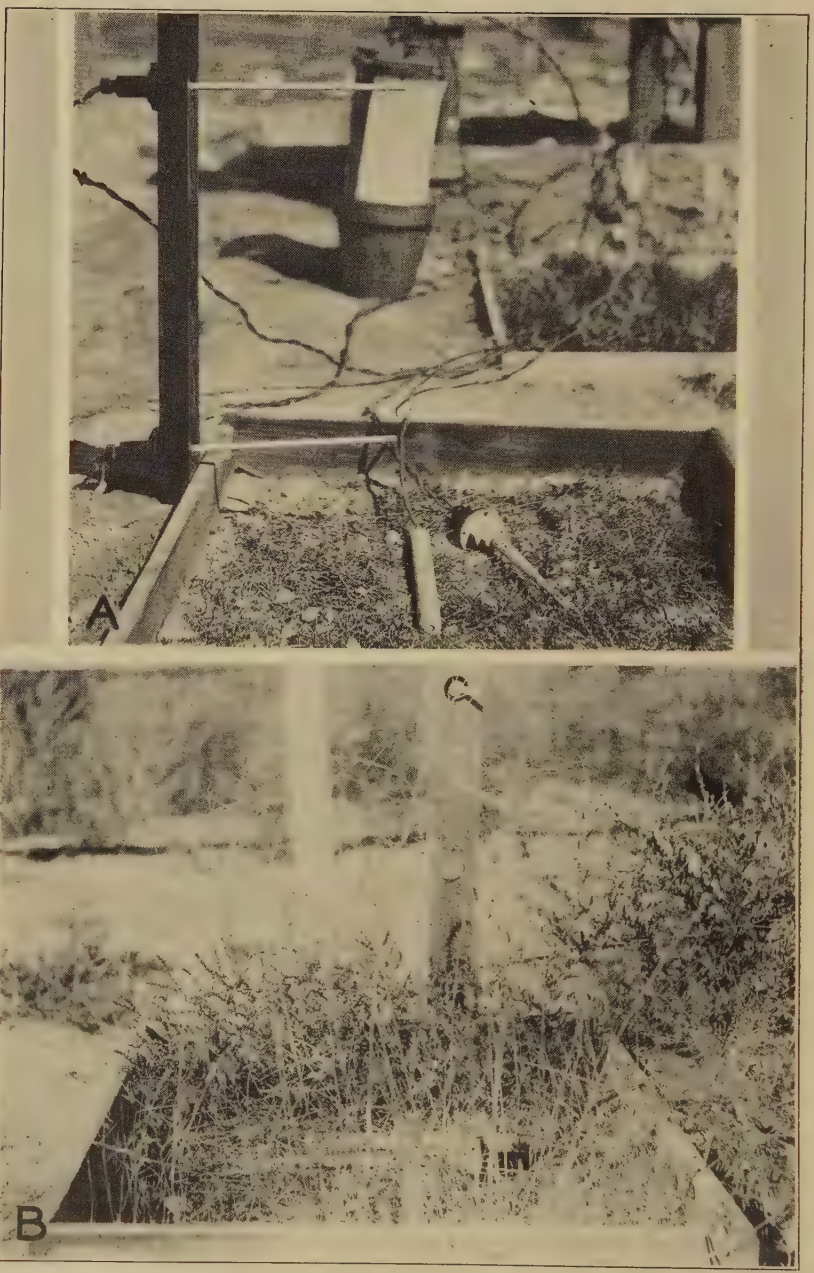
top, all provide an environment more favorable to the activity of *E. tenellus* than does a normal, well-advanced beet field.

Figure 4 presents thermograph records for the week ended May 7, 1928. A and B are for outdoor conditions and illustrate the differences in temperature between standard shade and the surface of the soil. The rapid heating of the soil surface is evident from the abrupt rise of the curve in B. It can readily be seen that, when expressed as areas on the record, the more effective temperature ranges cover a much greater percentage of the total area above a given base line than is the case for A. Figure 4, C, illustrates the conditions obtained experimentally. This temperature record occupies a position intermediate between the standard-shade and soil-surface records.

Table 2 is the record of winter temperatures for the three winters 1925–26, 1926–27, and 1927–28. In order to provide a proper basis for comparison, the record obtained from the soil thermograph is used throughout for soil-surface temperatures, since the electric resistance

RUSSIAN THISTLES, SUGAR BEETS, AND ABANDONED FARM

A, The stand of Russian thistle (*S. pestifer*) from which the data of Figure 2, B, were obtained; B, beet field from which the data of Figure 3 were obtained; C, abandoned farm in the vicinity of Twin Falls, Idaho, which is representative of the sites used for observation stations.



ELECTRIC-RESISTANCE THERMOMETERS AND SOIL THERMOGRAPHS

A. Electric-resistance thermometers and soil thermograph used in obtaining the winter data presented in Table 3; B, electric-resistance thermometer and soil thermograph in summer environment in the same location shown in A. The data are presented in Tables 4 and 5.

thermometer set-up was not available the first winter. These same data are graphically presented in Figures 5, 6, and 7. The striking thing during all three winters was the difference between soil-surface and standard-shade temperatures. In every case of low minimum

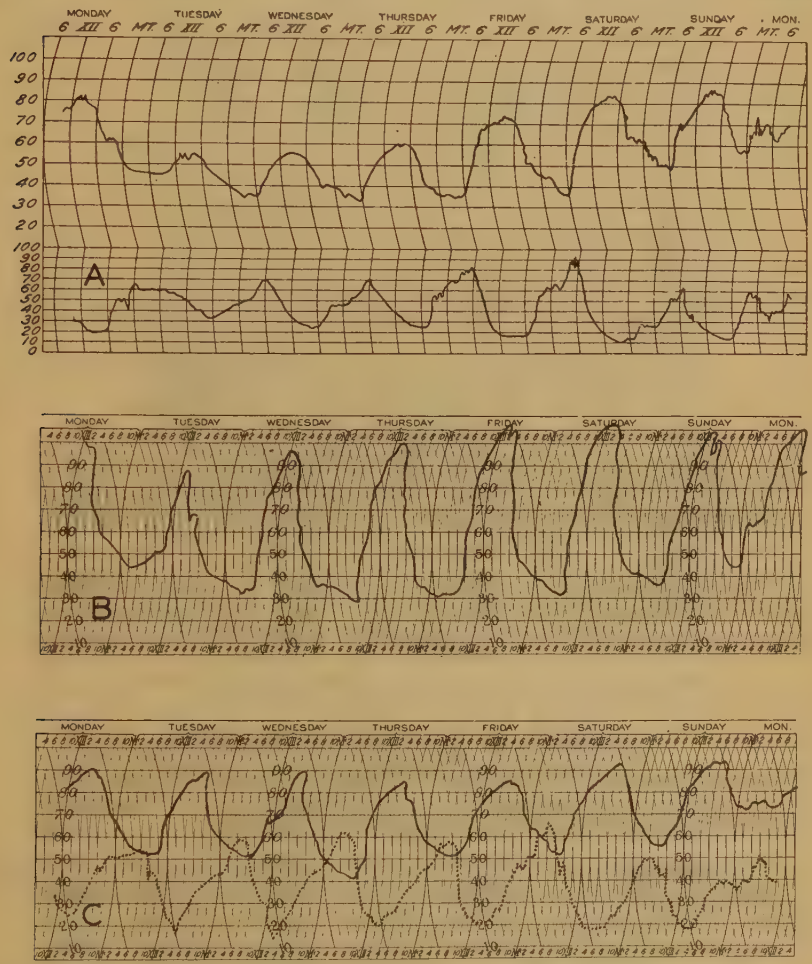


FIGURE 4.—Temperature and humidity records, week ended May 7, 1928, Twin Falls, Idaho: A, Hygrothermograph record, standard shade; B, soil-surface temperatures; C, hygrothermograph record from climate-simulation experiments

air temperatures the temperature at the soil surface was kept up by the insulating effect of snow cover. The pronounced differences between maxima for the 1925–26 season are probably due to the fact that a fence built to protect the thermograph against wandering stock sheltered the thermograph too well. During the winters of 1926–27 and 1927–28 the soil thermograph was in identically the same position. (Pl. 2, A.)

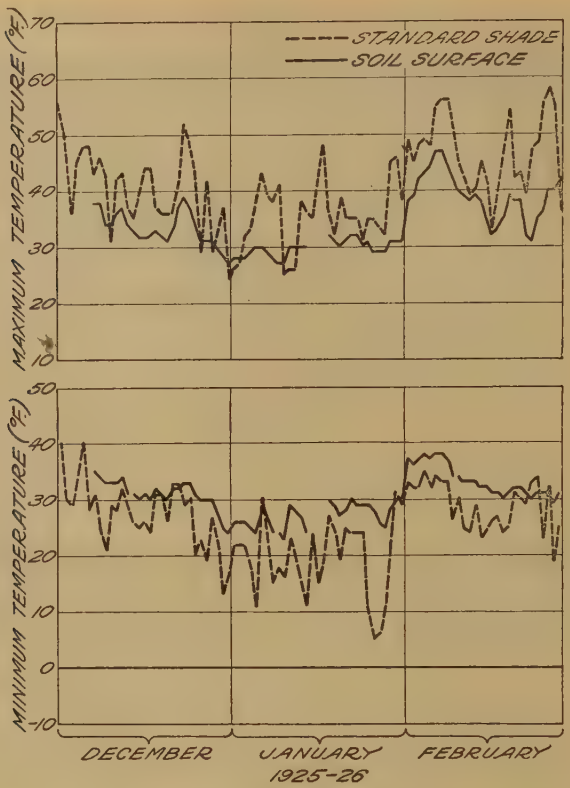


FIGURE 5.—Daily maximum and minimum temperatures at soil surface and in standard shade, Twin Falls, Idaho, winter of 1925–26

TABLE 2.—*Winter temperatures at Twin Falls, Idaho, 1925–26, 1926–27, and 1927–28*

Date	1925–26						1926–27						1927–28					
	Standard shade			Soil thermograph at surface			Standard shade			Soil thermograph at surface			Standard shade			Soil thermograph at surface		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Dec. 1	55	40	47	----	----	----	58	39	48	66	32	49	50	36	43	50	31	40
2	48	30	39	----	----	----	56	42	49	60	40	50	57	42	49	65	37	51
3	36	29	32	----	----	----	52	41	46	56	39	27	42	32	37	57	36	47
4	45	35	40	----	----	----	45	35	40	54	35	44	45	27	36	53	25	39
5	48	40	44	----	----	----	36	34	35	38	33	35	49	22	35	58	22	40
6	48	28	38	----	----	----	36	34	35	----	----	----	32	20	26	40	19	29
7	43	31	37	38	35	36	34	28	31	----	----	----	31	16	23	47	14	30
8	46	25	35	38	34	36	34	28	31	35	31	33	37	19	28	34	17	25
9	43	21	32	34	33	31	36	23	29	39	22	30	37	25	31	36	24	30
10	31	29	30	34	33	33	38	24	31	40	21	30	36	15	25	45	17	31
11	42	28	35	36	33	34	49	29	39	42	28	35	29	19	24	41	14	32
12	43	32	37	37	34	35	28	20	24	30	24	27	35	12	23	31	13	22
13	37	29	33	34	31	33	24	18	21	----	----	----	40	20	30	31	28	30
14	35	26	30	33	31	32	16	−4	5	----	----	----	26	17	21	29	23	26
15	39	25	32	32	30	31	22	−2	10	29	20	24	34	22	26	30	23	26
16	44	26	35	32	31	31	32	21	26	32	29	30	37	23	30	34	22	28
17	44	24	34	32	30	31	35	26	30	32	30	31	30	16	23	37	17	27
18	37	31	34	33	32	32	40	28	34	33	31	32	28	11	19	37	14	25

TABLE 2.—*Winter temperatures at Twin Falls, Idaho, 1925–26, 1926–27, and 1927–28*—Continued

Date	1925–26						1926–27						1927–28					
	Standard shade			Soil thermograph at surface			Standard shade			Soil thermograph at surface			Standard shade			Soil thermograph at surface		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Dec. 19	36	31	33	32	31	31	36	26	31	32	30	30	29	13	21	37	10	23
20	36	26	31	31	30	30	32	15	23	31	29	30	32	11	21	38	11	24
21	36	33	34	34	32	33	35	26	30	32	27	29	37	12	24	42	11	26
22	41	33	37	37	32	34	28	21	24	31	27	29	32	10	21	40	10	25
23	52	29	40	39	33	36	25	17	21	31	26	28	34	18	26	46	15	30
24	49	30	39	37	33	35	20	−10	5	30	24	27	32	10	21	37	11	24
25	43	20	31	34	31	32	24	14	19	30	27	28	35	14	24	40	13	26
26	29	23	26	31	30	30	24	18	21	31	28	29	35	13	24	44	11	27
27	42	19	30	31	30	30	28	22	25	31	27	29	38	16	27	33	29	31
28	29	27	28	31	30	30	27	4	15	30	25	27	39	28	33	32	27	29
29	32	22	27	30	28	29	32	4	18	31	25	28	32	20	26	34	21	27
30	37	13	25	29	25	27	30	10	20	31	25	28	24	8	16	30	14	22
31	24	16	20	27	24	25	35	12	23	30	24	27	16	1	8	----	----	----
Jan. 1	26	22	24	28	26	27	34	12	23	29	22	25	38	16	27	----	----	----
2	27	22	24	28	26	27	40	20	30	31	25	28	47	31	39	33	31	32
3	32	22	27	28	26	27	42	32	37	32	31	31	44	31	37	37	29	33
4	33	18	25	29	25	27	51	29	40	36	28	32	41	33	37	35	31	33
5	39	11	25	30	24	27	53	31	42	44	29	36	38	28	33	39	29	34
6	43	30	36	30	29	29	46	31	38	31	24	27	46	30	38	44	29	36
7	39	23	31	29	26	27	41	28	34	41	25	33	37	28	32	42	28	35
8	38	15	27	28	24	26	34	23	28	34	20	27	40	26	33	43	27	35
9	41	18	29	27	24	25	39	26	32	35	23	29	41	34	37	44	30	37
10	25	16	20	27	23	25	43	24	33	41	21	31	42	26	34	43	28	35
11	26	23	24	30	29	29	41	33	37	42	30	36	47	27	37	42	28	35
12	26	20	23	30	28	29	37	32	34	37	30	33	56	33	44	53	30	41
13	38	15	26	30	27	28	45	31	38	45	30	37	49	35	42	43	31	37
14	36	11	23	30	24	27	45	30	37	43	28	35	35	24	29	40	26	33
15	35	24	29	----	----	----	47	32	38	46	28	37	25	21	23	30	24	27
16	42	15	28	--	----	----	41	31	36	39	28	33	26	10	18	32	28	30
17	48	18	33	----	----	----	40	2o	34	36	25	30	28	14	21	32	26	29
18	36	27	31	32	30	31	37	31	34	37	28	32	32	5	18	33	29	31
19	32	24	28	31	29	30	39	30	34	37	30	33	29	3	18	32	20	26
20	39	19	29	30	27	28	36	15	26	33	22	27	26	6	16	34	20	27
21	35	25	30	31	28	29	15	−1	6	21	15	18	31	4	17	35	16	25
22	35	24	29	32	30	31	18	−11	3	19	5	12	38	7	22	32	16	24
23	35	24	29	32	29	30	18	−4	7	28	10	19	35	24	29	36	24	30
24	31	24	27	30	29	29	23	0	11	27	12	19	35	26	30	35	25	30
25	35	11	23	31	29	30	30	11	20	29	17	23	38	26	32	38	26	32
26	35	5	20	29	28	28	30	18	24	30	19	24	40	29	34	41	25	33
27	33	6	19	29	26	27	38	16	27	35	19	27	34	12	23	40	18	32
28	32	10	21	28	25	26	44	28	36	38	27	32	37	14	25	43	16	29
29	45	25	35	31	28	29	30	23	26	33	21	27	45	30	37	43	26	34
30	46	31	38	31	30	30	36	20	28	34	19	26	44	30	37	45	30	37
31	38	29	33	31	30	30	37	20	28	35	21	28	37	27	32	45	29	37
Feb. 1	49	33	41	38	37	37	44	32	38	40	32	36	35	26	30	36	29	32
2	45	32	38	39	36	37	49	35	42	46	32	39	42	28	35	44	30	37
3	48	32	40	42	37	39	44	33	38	41	30	35	46	27	36	40	29	34
4	49	35	42	43	38	40	45	31	38	41	34	37	52	33	42	54	29	41
5	48	32	40	44	37	40	40	26	33	37	24	30	44	29	36	47	28	37
6	55	34	44	47	38	42	40	29	34	38	26	32	40	29	34	48	28	38
7	56	33	44	47	38	42	38	25	31	37	27	32	39	24	31	47	27	37
8	56	33	44	45	37	41	34	26	30	35	24	29	37	26	31	47	27	37
9	51	33	38	42	34	38	32	19	25	30	19	24	38	22	30	50	25	37
10	45	26	32	40	34	37	31	14	22	30	14	22	40	21	30	50	24	37
11	42	30	33	39	33	36	28	19	24	32	17	24	46	20	32	50	23	36
12	39	25	31	38	33	35	30	21	25	36	20	28	35	23	29	44	23	33
13	40	24	32	39	33	36	33	23	28	34	22	28	38	30	34	55	20	37
14	45	29	34	38	32	35	41	17	29	38	14	26	33	23	28	38	28	33
15	42	23	33	35	32	33	50	31	40	46	30	38	30	7	18	38	24	31
16	33	24	29	32	31	31	44	35	39	44	31	37	40	18	29	46	22	34
17	39	26	33	33	31	32	46	33	39	47	30	38	44	25	34	58	25	41
18	47	27	35	35	30	32	45	34	39	40	29	34	44	21	32	57	24	40
19	54	24	39	39	31	35	39	31	35	34	27	30	46	25	35	60	25	42
20	42	25	36	38	32	35	48	35	41	42	32	37	49	23	36	64	28	46
21	43	31	36	38	32	35	48	37	42	48	32	40	44	23	33	53	27	40
22	39	30	34	32	31	31	48	35	41	50	31	40	38	30	34	48	30	39
23	47	29	40	31	30	30	46	28	37	43	26	34	37	23	30	52	25	38
24	48	33	41	35	31	33	42	26	34	42	25	33	35	25	30	62	28	45
25	55	34	39	36	31	33	44	32	38	49	30	39	30	22	26	34	27	30
26	58	23	45	40	31	35	46	30	38	49	29	39	40	24	32	57	25	41
27	55	32	37	40	30	35	42	31	36	45	29	37	45	30	37	60	24	42
28	36	19	30	41	31	36	43	29	36	45	26	35	35	29	32	42	29	35
		25																

Table 3 records data obtained during the winter months in connection with hibernation studies. The data for 1927–28 are more complete than those for 1926–27 in that readings were taken through the vertical range of the environment, so that the temperature records were obtained for four points—soil surface, 6 inches above the surface, 27 inches above the surface, and the standard shade of a Weather Bureau shelter. A study of these records reveals an interesting picture of the temperature relations existing within this vertical range. The 6-inch level was consistently the coldest; on the other hand, the maxima at that height were higher than at any of the other points.

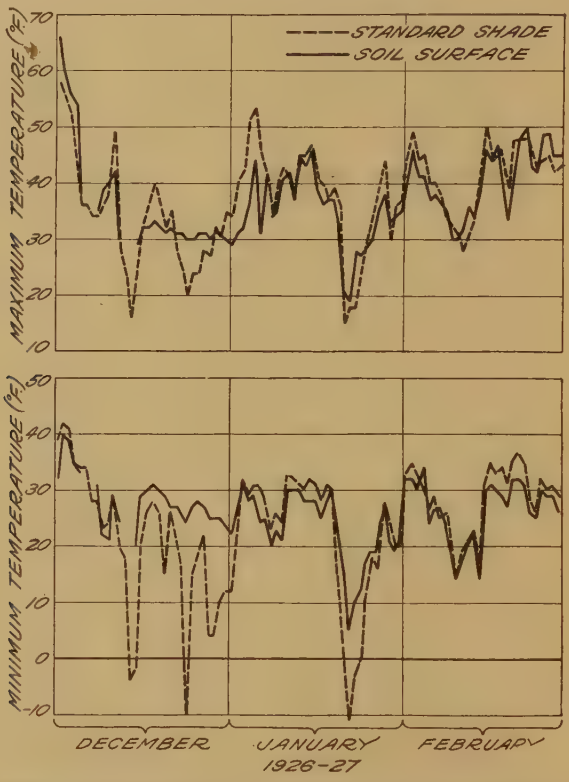


FIGURE 6.—Daily maximum and minimum temperatures at soil surface and in standard shade, Twin Falls, Idaho, winter of 1926–27

Above 6 inches the air cools off as reflection from the earth's surface is dissipated, and thus the maxima decrease. The minima increase as the cold air sinks to the lower levels. The soil surface, protected often by a thin snow covering, has the highest minima and the lowest maxima.

There is a close similarity between the mean temperatures of the soil surface and standard shade for both winters. By comparing this season with that of 1926–27, it will be observed that the daily records from standard shade and soil surface differ widely, particularly with respect to minima. The temperatures at the soil surface are evidently highly "buffered" against great extremes, and this fact is of the greatest importance in considering temperature in relation to insect hibernation.

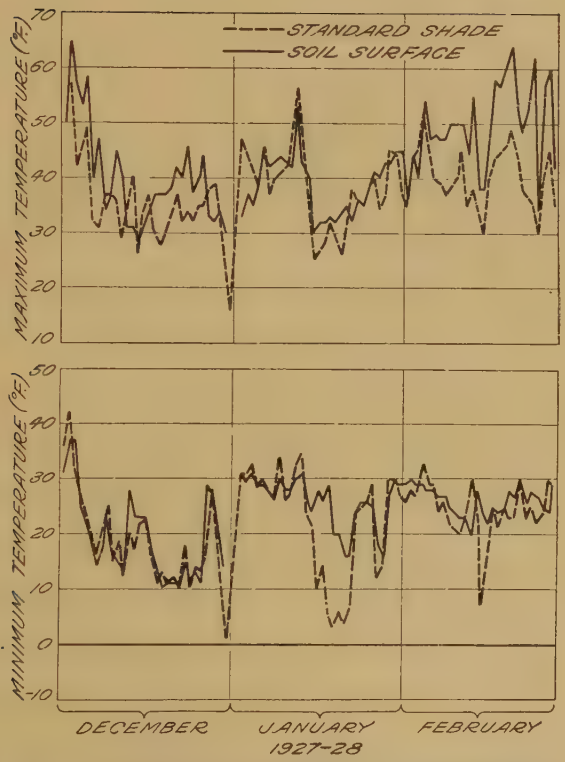


FIGURE 7.—Daily maximum and minimum temperatures at soil surface and in standard shade, Twin Falls, Idaho, winter of 1927–28

TABLE 3.—*Winter temperature records at Twin Falls, Idaho, 1926–27 and 1927–28, taken in connection with hibernation studies of Eutettix tenellus*

Date	1926–27									1927–28														
	Standard shade			Soil surface in hibernation cage			Soil surface in open			Soil surface in open			6 inches above surface			27 inches above surface			Soil surface in hibernation cage			Standard shade		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Dec. 1	58	39	48	55	38	46	62	32	47	49	29	39	49	30	39	50	32	41	48	33	40	50	36	43
2	56	42	49	52	42	47	57	36	46	65	34	49	66	36	51	60	38	49	61	37	49	57	42	49
3	52	41	46	47	40	43	52	40	46	57	27	42	58	29	43	46	30	38	49	30	39	42	32	37
4	45	35	40	50	38	44	54	32	43	55	25	40	67	20	38	52	23	37	55	25	40	45	27	36
5	36	34	35	39	32	35	40	35	37	56	22	39	56	17	36	53	20	36	58	23	40	49	22	35
6	36	34	35	38	35	37	42	32	37	41	18	29	33	16	24	30	18	24	35	20	27	32	20	26
7	34	28	31	35	33	34	35	29	32	46	13	29	39	11	25	34	13	23	41	16	28	32	16	24
8	34	28	31	------	------	------	------	------	------	32	18	25	34	13	23	35	16	25	35	19	27	37	19	28
9	36	23	29	------	------	------	------	------	------	33	26	29	35	18	25	36	20	28	37	25	31	37	25	31
10	38	24	31	------	------	------	------	------	------	40	20	30	47	8	27	39	10	24	40	15	27	36	15	25
11	49	29	39	------	------	------	------	------	------	40	19	29	42	12	27	35	9	22	40	13	26	29	19	24
12	28	20	24	32	28	30	28	25	26	32	14	23	32	6	19	36	7	21	33	13	23	35	12	23
13	24	18	21	30	25	27	30	28	29	30	28	29	35	19	27	38	22	30	33	24	28	40	20	30
14	15	−4	5	30	20	25	27	23	25	28	25	27	25	11	18	31	13	22	29	22	25	26	17	21
15	22	−2	10	31	26	28	30	28	29	28	25	26	33	16	24	33	16	24	29	25	27	34	22	28
16	32	21	26	32	29	30	32	32	32	30	28	29	38	14	26	37	14	25	34	25	29	37	23	30
17	35	26	30	33	30	31	32	32	32	29	21	25	39	7	23	33	11	22	33	13	23	30	16	23
18	40	28	34	40	31	35	33	30	31	28	18	23	42	4	23	31	5	18	34	16	25	28	11	19
19	36	26	31	38	31	34	33	32	32	25	15	20	37	1	19	31	4	17	31	14	22	29	13	21
20	32	15	23	36	28	32	34	30	32	26	15	20	39	5	22	35	12	23	32	15	23	32	11	21
21	35	26	31	34	31	33	33	31	32	28	10	19	37	8	22	42	8	25	37	15	26	37	12	24
22	28	21	24	36	28	32	34	30	32	29	10	19	45	4	24	36	6	21	37	14	25	32	10	21
23	25	17	21	32	24	28	34	32	33	33	17	25	49	15	32	40	17	28	39	16	27	34	18	26
24	20	−10	5	30	21	26	32	25	28	29	7	18	42	6	24	35	7	21	35	14	24	32	10	21
25	24	14	19	30	22	26	32	22	27	30	12	21	42	11	28	39	12	25	36	12	24	35	14	24
26	24	18	21	40	27	32	30	27	28	30	9	19	45	10	27	38	9	23	42	12	28	35	13	24
27	28	22	25	35	23	29	38	28	33	27	25	26	39	26	32	37	26	31	32	25	28	38	16	27
28	27	4	15	34	27	30	32	30	31	------	------	------	------	------	------	------	------	------	------	------	------	39	28	33
29	32	4	18	33	25	29	30	20	25	28	22	25	41	15	28	36	18	27	32	23	27	32	20	26
30	30	10	20	35	22	28	31	22	26	27	20	23	39	5	22	30	7	18	30	7	18	24	8	16
31	35	12	23	36	21	28	30	29	29	20	14	17	25	−6	9	18	−3	8	24	10	17	16	1	8
Mean	34	21	------	37	32	------	36	29	------	35	20	------	41	13	------	37	15	------	38	19	------	36	19	------

Jan. 1	34	12	23	37	27	32	35	23	29	25	19	22	33	13	24	32	17	24	32	16	24	38	16	27
2	40	20	30	33	26	29	31	26	28	29	23	26	51	26	38	44	30	37	42	30	36	47	31	39
3	42	32	37	40	29	34	37	31	34	30	26	28	49	21	35	48	24	36	44	27	35	44	31	37
4	51	29	40	43	30	36	42	30	36	33	30	31	43	30	36	43	32	37	40	32	36	41	33	37
5	54	31	42	42	30	36	44	31	37	35	30	32	46	21	33	42	25	33	42	29	35	38	28	33
6	46	31	38	43	30	36	45	31	38	39	29	34	53	22	37	49	26	37	47	29	38	46	30	38
7	41	28	34	39	29	34	50	28	39	42	28	35	45	20	32	40	24	32	44	28	36	37	28	32
8	34	23	28	32	29	31	40	26	33	46	25	35	48	19	33	43	22	32	46	26	36	40	26	33
9	39	26	32	40	30	35	37	32	34	46	25	35	49	21	35	43	23	33	45	28	36	41	34	37
10	43	24	33	42	29	35	37	30	33	43	26	34	50	20	35	46	22	34	46	27	36	42	26	34
11	41	33	37	33	31	32	35	30	32	43	26	34	53	21	36	51	22	36	47	27	37	47	27	37
12	37	32	34	39	30	34	40	32	36	52	29	40	63	31	47	59	35	47	57	34	45	56	33	44
13	45	31	38	45	31	38	45	32	38	41	30	35	55	32	43	55	33	44	51	33	42	49	35	42
14	45	30	37	46	30	38	50	29	39	43	27	35	43	20	31	38	22	30	39	27	33	35	24	29
15	47	32	39	42	31	36	60	30	45	31	25	28	28	17	22	29	20	24	30	25	27	25	21	23
16	41	31	36	50	31	40	55	30	42	31	29	30	45	3	24	35	5	20	41	17	29	26	10	18
17	40	28	34	47	31	39	51	28	39	31	27	29	43	3	23	41	7	24	43	19	31	28	14	21
18	37	31	34	38	30	34	40	29	34	29	25	27	46	4	25	35	5	20	42	16	29	32	5	18
19	39	30	34	37	31	34	39	30	34	30	22	26	45	−1	22	38	1	19	42	13	27	29	3	16
20	36	15	25	35	26	30	32	27	29	28	23	25	46	2	24	34	4	19	43	13	28	26	6	16
21	15	−1	7	33	20	26	48	24	36	27	20	23	47	2	24	39	3	21	45	10	27	31	4	17
22	18	−11	4	28	19	23	33	22	27	28	20	24	39	2	20	39	4	21	35	12	23	38	7	22
23	18	−4	7	33	22	27	31	23	27	30	25	27	41	15	28	37	18	27	40	23	31	35	24	29
24	23	-----	11	30	19	24	31	23	27	29	25	27	41	21	31	40	24	32	40	26	33	35	26	30
25	30	11	20	36	21	28	36	26	31	31	26	29	46	21	33	43	23	33	43	25	34	38	26	32
26	30	18	24	32	25	28	32	25	28	30	28	29	48	12	30	47	14	30	50	21	35	40	29	34
27	38	16	27	36	26	31	33	26	29	30	23	26	46	8	27	40	11	25	44	17	30	34	12	23
28	44	28	36	35	30	32	40	32	36	31	21	26	50	7	26	48	10	29	51	15	33	37	14	25
29	30	23	26	35	29	32	32	28	30	32	28	30	56	23	39	48	25	36	50	28	39	45	30	37
30	36	20	28	41	28	34	36	26	31	39	30	34	55	25	40	54	28	42	47	29	38	44	30	37
31	37	20	28	37	27	32	36	23	29	47	29	38	45	23	34	44	27	35	47	29	38	37	27	32
Mean	37	22	-----	38	28	-----	40	28	-----	35	22	-----	47	16	-----	43	19	-----	44	23	-----	38	22	-----
Feb. 1	44	32	38	38	34	36	38	32	35	37	28	32	40	22	31	39	25	32	38	28	33	35	26	30
2	49	35	42	45	32	38	49	35	42	44	27	35	49	24	36	47	27	37	45	29	37	42	28	35
3	44	33	38	38	31	34	40	32	36	40	27	35	49	22	35	49	26	37	42	28	35	46	27	36
4	45	31	38	40	30	35	42	29	35	59	27	43	62	25	43	59	29	44	55	30	42	52	33	42
5	40	26	33	41	29	35	42	28	35	52	28	40	50	22	36	49	26	37	49	26	37	44	29	36
6	40	29	34	45	30	37	45	30	37	54	27	40	-----	-----	-----	44	27	35	45	29	37	40	29	34
7	38	25	31	48	28	38	55	28	41	49	26	32	-----	-----	-----	48	22	35	50	25	37	39	24	31
8	34	25	30	44	27	35	44	27	35	50	24	37	-----	-----	-----	45	22	33	48	25	36	37	26	31
9	32	19	25	39	27	33	50	25	37	49	22	35	-----	-----	-----	41	18	29	46	20	33	38	22	30
10	31	14	22	40	26	33	51	19	35	53	21	37	-----	-----	-----	43	16	29	45	20	32	40	21	30
11	28	19	23	34	27	30	39	21	30	52	21	36	-----	-----	-----	51	16	33	52	21	36	45	20	32
12	30	21	25	37	22	29	40	24	32	52	19	35	-----	-----	-----	39	19	29	41	21	31	35	23	29
13	33	23	28	36	29	32	40	24	32	65	6	35	-----	-----	-----	50	3	26	55	8	31	38	30	34
14	41	17	29	-----	-----	-----	-----	-----	-----	46	27	36	-----	-----	-----	40	16	28	38	23	30	33	23	28
15	50	31	40	41	31	36	56	31	43	31	25	28	-----	-----	-----	37	5	21	39	12	25	30	7	18
16	44	35	39	46	34	40	56	35	45	43	25	34	-----	-----	-----	45	17	31	45	21	33	40	19	29
17	46	33	39	50	31	40	56	30	43	60	23	41	-----	-----	-----	52	23	37	52	26	39	44	25	34
18	45	34	39	38	31	34	43	30	36	65	23	41	60	18	39	58	23	40	60	25	37	45	21	33

TABLE 3.—*Winter temperature records at Twin Falls, Idaho, 1926–27 and 1927–28, taken in connection with hibernation studies of Eutettix tenellus*—Continued

Date	1926–27									1927–28														
	Standard shade			Soil surface in hibernation cage			Soil surface in open			Soil surface in open			6 inches above surface			27 inches above surface			Soil surface in hibernation cage			Standard shade		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Feb. 19	39	31	35	33	31	32	36	30	33	64	26	45	59	20	39	56	24	40	58	26	42	46	25	35
20	48	35	41	40	32	36	43	33	38	62	25	43	66	16	41	59	20	39	62	23	47	49	23	36
21	49	37	43	61	40	50	66	36	51	56	26	41	57	18	37	55	21	38	52	23	37	44	23	33
22	48	35	41	56	35	45	62	31	46	57	29	43	47	29	38	47	32	38	44	21	32	38	30	34
23	46	28	36	43	30	36	45	29	36	65	26	45	52	18	35	48	22	35	49	24	36	37	23	30
24	42	26	34	59	29	44	62	27	44	67	27	47	55	27	41	49	27	38	52	28	40	35	25	30
25	44	32	38	52	33	42	60	31	45	34	28	31	38	22	30	37	25	31	37	27	32	30	22	26
26	46	30	38	55	33	44	65	29	47	65	27	46	55	15	35	50	20	35	50	23	36	40	24	32
27	42	31	36	52	32	42	57	30	43	64	19	41	65	14	39	55	18	31	56	22	39	45	30	37
28	43	29	36	60	32	46	70	29	49	42	28	35	42	25	33	43	28	35	42	29	35	35	29	32
29													39	26	32	41	31	36	39	32	35	35	31	33
Mean	41	28	------	45	31	------	50	28	------	53	25	------	52	21	------	47	21	------	48	24	------	40	25	------

Table 4 records temperature data taken during the season of 1927 through the same vertical range as recorded during the preceding winter (Table 3). For purposes of comparison, the standard-shade readings for 1926 are added. Table 5 gives the data in greater detail for the first two months. (Pl. 2, B.)

TABLE 4.—*Temperature records for the period of activity of Eutettix tenellus at Twin Falls, Idaho, March–November, 1926 and 1927*

Week ended	Standard-shade temperatures (thermograph in Weather Bureau shelter)						Free-air temperatures in 1927 (electric-resistance thermometers and Engelhardt recorder)											
	1926			1927			Soil surface				6 inches above surface				27 inches above surface			
	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily means computed from hourly means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily means computed from hourly means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily means computed from hourly means
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Mar. 8	50	22	36	52	28	40	74	31	52	46	----	----	----	----	----	----	----	----
15	41	30	36	48	28	38	68	32	50	42	----	----	----	----	----	----	----	----
22	59	33	46	41	25	33	58	28	43	42	----	----	----	----	----	----	----	----
29	52	28	40	53	31	42	80	27	53	44	----	----	----	----	----	----	----	----
Mean	50	28	----	48	28	----	70	29	----	----	----	----	----	----	----	----	----	----
Apr. 5	47	27	37	51	31	41	74	29	51	44	86	34	60	49	----	----	----	----
12	60	35	47	50	30	40	84	30	57	47	85	29	57	56	----	----	----	----
19	71	40	55	49	31	40	70	29	49	42	75	35	55	51	54	32	43	42
26	67	40	53	61	30	45	80	24	52	43	----	----	----	----	59	23	41	44
Mean	61	35	----	52	30	----	77	28	----	----	----	----	----	----	----	----	----	----
May 3	76	45	60	70	41	55	92	30	61	53	81	33	57	54	69	27	48	49
10	61	39	50	57	36	46	96	37	66	54	76	37	56	51	68	37	52	49
17	70	42	56	76	44	60	105	43	74	66	101	43	72	59	87	44	65	65
24	75	48	61	57	38	47	80	36	58	53	80	41	60	59	66	39	52	50
31	68	44	56	61	39	50	99	43	71	62	92	42	67	63	84	43	63	60
Mean	70	44	----	64	40	----	94	38	----	----	86	39	----	----	75	38	----	----
June 7	84	50	67	71	42	56	95	51	73	64	95	50	72	65	83	47	65	62
14	81	55	68	77	49	63	[1] 110	55	83	78	108	50	79	76	102	52	82	75
21	72	45	58	81	51	66	109	50	79	75	101	47	74	71	93	49	71	69
28	95	51	73	82	51	66	110	51	80	80	108	56	82	80	101	49	75	76
Mean	83	50	----	78	48	----	106	52	----	----	103	50	----	----	95	49	----	----
July 5	90	58	74	80	55	67	110	50	80	77	99	47	73	70	95	50	72	71
12	81	55	68	89	54	71	110	51	80	81	107	47	77	75	101	56	75	76
19	94	60	77	86	54	70	110	60	85	81	103	50	76	74	96	53	74	74
26	86	51	68	91	57	74	110	57	83	82	107	53	80	78	103	56	79	77
Mean	88	56	----	86	55	----	110	54	----	----	106	49	----	----	99	52	----	----
Aug. 2	89	57	73	90	56	73	110	54	82	81	108	51	79	76	99	54	76	75
9	86	58	72	88	53	71	110	53	81	81	103	49	76	76	100	52	76	74
16	86	54	70	76	48	62	110	49	74	79	110	46	78	74	103	49	76	75
23	80	54	67	89	55	72	110	75	92	94	107	50	78	75	91	45	68	68
30	87	55	71	83	48	65	110	74	92	94	107	46	76	72	----	----	----	----
Mean	86	56	----	85	52	----	110	61	----	----	107	48	----	----	98	50	----	----

[1] Limit of machine's capacity to register.

TABLE 4.—*Temperature records for the period of activity of Eutettix tenellus at Twin Falls, Idaho, March–November, 1926 and 1927*—Continued

Week ended	Standard-shade temperatures (thermograph in Weather Bureau shelter)						Free-air temperatures in 1927 (electric-resistance thermometers and Engelhardt recorder)											
	1926			1927			Soil surface				6 inches above surface				27 inches above surface			
	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily means computed from hourly means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily means computed from hourly means	Average of daily maxima	Average of daily minima	Average of daily means	Average of daily means computed from hourly means
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Sept. 6	71	42	56	78	48	63	110	46	78	60	96	43	69	55	88	43	65	54
13	77	42	59	69	42	55	98	39	68	60	79	38	58	53	71	38	54	54
20	70	40	55	75	45	60	106	37	71	62	93	35	64	58	84	37	60	57
27	62	27	44	69	38	53	109	47	78	65	88	41	64	59	81	42	61	59
Mean	70	38	----	75	43	----	106	42	----	------	89	39	----	------	81	40	----	------
Oct. 4	64	35	49	61	44	52	91	36	63	53	73	36	54	52	66	38	52	50
11	68	34	51	59	30	44	91	24	57	49	72	27	49	47	63	27	45	44
18	71	39	55	74	35	54	99	28	63	53	72	29	50	48	75	30	52	51
25	69	36	52	80	35	57	105	30	67	56	89	29	59	53	83	32	57	54
Mean	68	36	----	68	36	----	96	29	----	------	76	30	----	------	72	32	----	------
Nov. 1	60	34	47	55	39	47	74	41	57	50	69	41	55	47	85	43	54	48
8	58	28	43	63	40	51	----	----	----	------	----	----	----	------	----	----	----	------
15	53	30	41	45	33	39	----	----	----	------	----	----	----	------	----	----	----	------
22	49	32	40	52	35	45	58	33	45	39	56	31	43	40	56	33	44	41
29	48	37	42	50	36	42	53	29	41	35	54	28	41	35	52	31	41	37
Mean	54	32	----	53	37	----	61	34	----	------	59	33	----	------	64	36	----	------

TABLE 5.—*Daily temperature maxima and minima for March, April, and May, 1927, at Twin Falls, Idaho*

Date	Standard shade			Soil surface					
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Average of hourly means	Ratio of standard shade to soil surface	Solar radiation per square centimeter
	°F.	°F.	°F.	°F.	°F.	°F.	°F.		*Gram calories*
Mar. 1	55	27	41	75	29	53	50	0.73	----
2	59	29	44	83	31	57	47	.73	----
3	60	26	43	82	30	56	49	.73	----
4 [1]	47	28	37	55	34	42	44	.85	----
5	46	28	37	67	30	48	41	.68	----
6	47	34	40	86	32	59	45	.54	----
7	54	25	39	----	----	----	----	----	----
8 [1]	50	30	40	59	35	47	44	.84	----
9 [1]	38	25	31	63	33	48	39	.60	----
10	42	22	32	76	28	52	42	.55	----
11	45	27	36	77	34	55	43	.58	----
12	59	30	44	----	----	----	----	----	----
13 [1]	61	37	49	----	----	----	----	----	----
14 [1]	47	28	37	----	----	----	----	----	----
15 [1]	34	25	29	----	----	----	----	----	----
16	40	22	31	----	----	----	----	----	----
17 [1]	37	28	32	47	29	38	33	.78	----
18 [1]	37	23	30	34	28	31	----	1.08	----
19 [1]	39	25	32	----	----	----	----	----	----

[1] Precipitation.

TABLE 5.—*Daily temperature maxima and minima for March, April, and May, 1927, at Twin Falls, Idaho*—Continued

Date	Standard shade			Soil surface					
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Average of hourly means	Ratio of standard shade to soil surface	Solar radiation per square centimeter
	°F.	°F.	°F.	°F.	°F.	°F.	°F.		*Gram calories*
Mar. 20	46	24	35	69	28	48	47	0.66	
21	49	31	40	84	28	56	46	.70	
22	52	35	43	75	28	51	43	.69	
23	60	30	45	92	25	58	48	.65	
24	48	33	40	73	28	50	45	.65	
25	50	23	36	85	20	52	43	.58	
26	49	31	40	80	30	55	45	.61	
27	59	32	45	74	31	52	47	.79	
28 [1]	53	35	44	81	30	55	43	.65	
29	58	27	42	97	25	61	38	.59	
30 [1]	58	25	36	95	25	60	46	.61	
31	48	37	42	57	31	44	42	.85	
Apr. 1 [1]	48	32	40	63	30	46	42	.76	
2 [1]	54	36	45	67	35	51	46	.80	294.9
3 [1]	45	31	36	66	28	47	42	.68	355.6
4	51	29	40						
5	57	28	42	93	26	59	49	.61	649.9
6 [1]	58	38	48	93	34	63	53	.62	611.8
7	62	38	50	97	33	65	55	.63	622.2
8 [1]	49	33	41	78	34	56	44	.62	359.1
9 [2]	41	22	31	71	30	50	36	.57	372.8
10 [1]	46	16	31	75	26	50	41	.61	683
11 [2]	37	30	33						439.6
12 [1]	44	32	38						382
13 [1]	46	32	39						289.1
14	57	29	43						666.3
15 [1]	57	35	46	76	32	54	44	.75	404.7
16	45	30	37	69	29	49	41	.65	641.4
17	51	23	42	75	31	53	44	.68	590
18 [1]	48	30	39	62	26	44	40	.77	308.4
19 [1]	41	38	39	57	22	39	37	.71	416.5
20	47	19	33	81	20	50	38	.58	735.7
21	61	18	39						677.7
22	64	36	50						438.3
23	64	35	49	104	32	68	55	.61	701.4
24	74	31	52						734.6
25	81	37	59						737.2
26	85	40	62	110	35	72	61	.77	567.5
27	71	50	60	89	42	65	55	.79	323
28	70	43	56						717.7
29	70	40	55	99	35	67	55	.70	748.2
30	76	36	56	99	29	64	53	.76	704.7
May 1	67	43	55	65	12	38	33	1.03	273.6
2	55	38	46						673.5
3	66	32	49						573
4	60	38	49	100	36	68	57	.60	689
5	60	36	48	110	33	71	60	.54	675
6 [1]	60	42	51	110	42	76	58	.54	478.4
7 [2]	46	36	41	72	41	56	45	.63	147.8
8 [2]	51	34	42	70	32	51	44	.72	200
9	56	39	47	92	34	63	51	.60	451.7
10	64	39	56	100	38	69	56	.64	539.5
11 [1]	62	46	54	92	44	68	61	.67	715.4
12	68	45	56	95	42	68	61	.71	712
13	76	43	59	107	43	75	68	71	740.3
14	86	44	65	110	45	77	71	.78	840.5
15	87	46	66	110	46	78	71	.79	719.2
16	88	47	67	110	46	78	74	.80	700
17	90	41	56	84	38	61	61	.93	798.5
18	60	37	48	84	36	60	56	.71	537.7
19 [2]	58	40	49	70	41	55	49	.82	309
20	51	35	43						546.4
21 [1]	49	35	42	78	34	56	48	.62	323.2
22 [1]	56	36	46	85	35	60	51	.65	
23 [1]	61	42	51	84	41	62	55	.72	
24	70	46	58	90	43	66	63	.77	
25 [1]	80	42	61	110	42	76	65	.72	
26	62	46	54	91	45	68	61	.68	
27 [1]	61	38	49	97	45	71	59	.62	
28 [2]	46	33	39						
29	52	36	44	70	37	53	51	.74	
30 [1]	59	38	48						
31 [1]	58	38	48	83	40	61	61	.69	

[1] Precipitation.

[2] Heavy precipitation (0.25 inch).

The absorption of heat by the soil and the gradual dissipation of reflected heat as the distance from the soil is increased is clear from the record. The record for the early months is of especial significance. There is a marked difference in mean maxima for the months of March and April between standard-shade and soil-surface temperatures. While the standard-shade thermograph was recording temperatures below or barely at the temperature of activity, the insect had available temperatures ranging from favorable to almost optimum. Since these records were taken at a point considered an average of a typical environment, it can readily be seen that even a slightly more favorable position (south slope, sandy soil) would bring the insect to optimum temperature conditions for a portion of the day. By comparing the standard-shade temperatures of 1927 with those of 1926, it will be noted that the latter had maxima very much higher than the former. Since it can be reasonably considered axiomatic that temperatures in the same place in the same environment bear the same relationship to standard-shade temperatures from year to year (excluding such considerations as changed covering, plant successions, etc.), optimum temperatures must have prevailed under the 1926 condition early in the season to a much greater extent than in 1927. As a matter of fact, the migration of *E. tenellus* into the beet fields occurred earlier in 1926 than in any other year for which records are available.

The spring of 1927 was decidedly cooler than that of 1926, as reference to Tables 4 and 6 will show. In spite of this, however, the data of Table 4 indicate that optimum temperature conditions prevailed in 1927 in May. When optimum temperatures have been reached, any further warming up of the environment is not necessarily followed by a diminished activity on the part of the insect, since within the vertical range of the environment there are temperatures available still within optimum limits. The data for June, July, and August illustrate how the seasonal march of temperature gradually establishes optima through the vertical range, incidentally coincident with the vertical movement of the insect's food supply. In September and October of 1927, when the freshly germinated mustards at ground level were the sources of the insect's food supply, the optima still obtained at that point. As far as temperatures are concerned, the significant periods are in the early spring and fall; the only difference in total temperature effect between the two seasons will be due to the difference in time required to establish and disestablish the optimum. The conditions in the fall of the year leading to the disestablishment of the optima are significant, affecting as they do the size of the third generation and consequently the overwintering population.

Table 6 presents environmental data comparing the spring seasons of 1926 and 1927. Temperatures are recorded in terms of areas in square inches above the three base lines, 40°, 50°, and 60° F. These areas were measured with a polar planimeter, and the figures in the table represent the actual areas in square inches below the thermograph curve and above the three base lines. The spring of 1926 opened up much earlier than did that of 1927. The sunshine data also indicate this. Precipitation was similar in both years for March and April. The month of May in both years was characterized by abnormal rainfall, but in 1927 the plus deviation from the normal was very great.

TABLE 6.—*Comparison of meteorological data of the spring of 1926 with those of 1927, Twin Falls, Idaho*

Date	Measure of temperature in standard shade expressed as square inches of surface on the thermograph record between the curve and a given base line			Sky			Precipitation
Week ended	Above 40° F.	Above 50° F.	Above 60° F.	Clear	Partly cloudy	Cloudy	
1926	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Days*	*Days*	*Days*	*Inches*
Mar. 8	2.03	0.47	0				0
15	0	0	0				.26
22	3.44	.50	.18				(1)
29	1.87	.55	.06				.02
Accumulated total	7.34	1.52	.24	19	8	4	.28
Apr. 5	.86	.12	0				.06
12	2.26	1.06	.09				.61
19	5.24	3.00	1.07				.52
26	5.50	2.10	.57				0
Accumulated total	21.20	7.80	1.97	29	26	6	1.47
May 3	9.60	4.58	2.00				0
10	6.00	1.24	.33				.22
17	6.87	2.75	1.21				(1)
24	8.73	4.63	1.67				.08
31	6.10	3.13	1.00				.01
Accumulated total	58.50	24.13	8.18	39	47	6	1.78
June 7	10.97	7.40	5.75				(1)
14	8.73	5.58	2.57				(1)
Accumulated total	78.20	37.11	14.50				1.78
1927							
Mar. 7	1.05	.20	0				(1)
14	1.00	.20	0				(1)
21	.21	0	0				.24
28	1.53	.20	0				0
Accumulated total	3.79	.60	0	12	16	3	.24
Apr. 4	1.47	.20	0				.20
11	1.41	.209	0				.35
18	.93	.12	0				.83
25	4.07	1.32	.40				(1)
Accumulated total	11.67	2.449	.40	21	29	9	1.62
May 2	6.57	3.10	1.35				0
9	4.73	.61	0				1.20
16	7.17	3.80	1.70				(1)
23	3.06	1.08	.30				.30
30	4.03	1.52	.57				.74
Accumulated total	37.23	12.559	4.32	30	46	14	3.86
June 6	6.10	2.75	.87				.04
13	8.73	5.00	2.33				(1)
Accumulated total	52.06	20.309	7.52				3.90

[1] Trace.

Table 7 compares the spring seasons of 1927 and 1928 in greater detail than was possible for 1926 and 1927. (Table 6.) In Table 7 the soil-surface temperatures are also listed, in terms of square inches on the thermograph record, four bases, 40°, 50°, 60°, and 70° F., being used. March temperatures in 1928 were much higher than in 1927. This early opening up of the season in 1928 was important,

since it started the growth of desert host plants and initiated activity of the insect. Precipitation was heavier in March and April of 1928, but for the entire period considered it was much more uniformly distributed in 1927. Rainfall in 1928 during this period came in isolated storms with extremely dry periods between. Atmometer records are not available prior to the last week in April, but soil-moisture records (Table 40) give indications of the extremely drying winds during that month. Comparison of the evaporation records for the two seasons shows 31 per cent more evaporation in 1928 than in 1927. The atmometer cups and pyrheliometer used are shown in Plate 3.

TABLE 7.—*Comparison of meteorological data of the springs of 1927 and 1928, Twin Falls, Idaho*

Date	Measure of temperature in standard shade expressed as square inches of surface on the thermograph record between the curve and a given base line			Measure of temperature at soil surface expressed as square inches of surface on the thermograph record between the curve and a given base line				Solar radiation per square centimeter	Evaporation	Precipitation	Wind movement
Week ended	Above 40° F.	Above 50° F.	Above 60° F.	Above 40° F.	Above 50° F.	Above 60° F.	Above 70° F.				
1927	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Gram calories*	*C. c.*	*Inches*	*Miles*
Mar. 7	1.05	0.20	0	2.64	1.32	0.55	0			(1)	
14	1.00	.20	0	1.92	.58	.10	0			(1)	
21	.21	0	0	.73	.26	.04	0			0.24	
28	1.53	.20	0	3.33	2.75	1.01	.23			0	
Accumulated total	3.79	.60	0	8.62	4.91	1.70	.23			.24	
Apr. 4	1.47	.20	0	3.00	1.24	.43	.20			.20	
11	1.41	.209	0	3.29	1.90	1.16	.55	3,891.8		.35	
18	.93	.12	0	2.23	1.00	.32	0	3,416.7		.83	971.2
25	4.07	1.32	.40	4.66	2.37	1.27	.90	4,012.6	31.78	(1)	1,094.7
Accumulated total	11.67	2.449	.40	21.80	11.42	4.88	1.88	11,321.1	31.78	1.62	2,065.9
May 2	6.57	3.10	1.35	5.23	3.66	2.67	1.84	4,073.9	67.55	0	1,048.7
9	4.73	.61	0	5.38	3.12	1.94	1.30	4,316.3	27.08	1.20	1,180.9
16	7.17	3.80	1.70	8.90	6.00	3.38	2.27	4,718.6	45.66	(1)	839.4
23	3.06	1.08	.30	4.44	3.00	1.66	.72	3,214.8	48.14	.30	1,319.3
30	4.03	1.52	.57	6.21	3.40	2.00	.95		44.41	.74	1,447.2
Accumulated total	37.23	12.559	4.32	51.96	30.60	16.53	8.96	27,644.7	264.62	3.86	7,901.4
June 6	6.10	2.75	.87	9.30	5.50	2.69	1.66	1,285.3	37.61	.04	1,169.7
13	8.73	5.00	2.33	12.00	8.07	5.69	4.63	4,580.9	56.70	(1)	911.5
Accumulated total	52.06	20.309	7.52	73.26	44.17	24.91	15.25	33,510.9	358.93	3.90	9,982.6
1928											
Mar. 5	.21	0	0	.90	.41	.009	0			0	
12	1.80	.24	0	2.50	1.41	.72	.20			.70	
19	1.13	.34	0	3.92	2.55	1.41	.75			(1)	
26	3.50	1.41	.33	3.78	2.52	1.15	.70			.92	
Accumulated total	6.64	1.99	.33	11.10	6.89	3.289	1.65			1.62	

(1) Trace.

TABLE 7.—*Comparison of meteorological data of the springs of 1927 and 1928, Twin Falls, Idaho*—Continued

Date	Measure of temperature in standard shade expressed as square inches of surface on the thermograph record between the curve and a given base line			Measure of temperature at soil surface expressed as square inches of surface on the thermograph record between the curve and a given base line				Solar radiation per square centimeter	Evaporation	Precipitation	Wind movement
Week ended	Above 40° F.	Above 50° F.	Above 60° F.	Above 40° F.	Above 50° F.	Above 60° F.	Above 70° F.				
1928	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Gram calories*	*C. c.*	*Inches*	*Miles*
Apr. 2	1.00	0.12	0	1.24	0.41	0	0			0.56	
9	.58	0	0	3.18	1.63	.86	.26	2,912.4		.21	
16	1.81	.25	0	3.80	2.27	1.23	.38	2,425.6		.14	
23	1.83	.54	.006	4.48	2.60	1.79	.61	2,401.7		.05	1,180.8
30	5.89	3.07	.91	7.53	4.78	3.30	2.17	2,512.0	48.65	0	1,340.7
Accumulated total	17.75	5.97	1.246	31.33	18.58	10.469	5.07	10,251.7	48.65	2.58	2,521.5
May 7	6.09	3.39	1.66	5.54	4.37	4.32	3.12		69.12	0	1,173.9
14	5.87	4.34	1.85	13.40	10.18	7.30	5.13		62.40	(1)	1,014.7
21	7.81	5.30	1.73	14.52	11.35	8.86	6.43		52.13	.10	814.0
28	10.60	6.78	3.60	15.05	11.55	8.68	4.06		71.47	.06	918.9
Accumulated total	48.12	25.78	10.086	79.84	56.03	39.629	23.81		303.77	2.74	6,443.0
June 4	5.52	3.18	1.34	14.09	10.63	8.23	6.30		78.85	0	1,294.0
11	7.77	4.45	1.88	14.18	10.56	7.93	6.00		89.40	.53	1,135.4
Accumulated total	61.41	33.41	13.306	108.11	77.22	55.789	36.11		472.02	3.27	8,872.4

[1] Trace.

EFFECT OF THE PHYSICAL FACTORS ON EUTETTIX TENELLUS

EFFECTS OF TEMPERATURE AND DIFFERENT KINDS OF LIGHT ON PREOVIPOSITION PERIOD

The preoviposition period of *E. tenellus* is a matter of much interest Dissections of females from the field to determine the progress of egg development were made throughout the seasons covered by this study.

Dissections of females captured in the field in the fall show that the ovaries of hibernating females are not developed. Rare exceptions to this occur. The ovaries apparently remain undeveloped until the latter part of February or early March, when signs of development become common among the hibernants. This development of ovaries in the hibernating females is apparently not entirely a matter of temperature effect, but must be preceded by a rest period for the ovary. The third brood of *E. tenellus* was active during the unusually warm October and November of 1927, but no changes were observed in the ovaries during that time. This quiescence of the ovaries was not due to lack of fertility of the female, since sperm sacs of these females contained sperm.

Data on the length of the preoviposition period from specimens kept in the dark at constant temperatures are listed in Table 8. In this table the source of the females used is given at the head of each column. "Laboratory-reared material" consisted of females which were not more than 24 hours old when taken from the breeding cages. The colonies in these cages were old and had been maintained in the greenhouse for a long time.

TABLE 8.—*Preoviposition periods of Eutettix tenellus kept at different temperatures, showing numbers of days required to reach certain stages of development*

Temperature	Laboratory-reared material			Summer material			Hibernants (late fall)			Hibernants (January, 1928)		
	No development in—	Ovaries developed in—	Mature eggs in—	No development in—	Ovaries developed in—	Mature eggs in—	No development in—	Ovaries developed in—	Mature eggs in—	No development in—	Ovaries developed in—	Mature eggs in—
°F.	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
55								72		28, 28, 24, 9, 28, 24, 28, 28, 24	28, 28	
57							38, 51, 52, 60	37, 52				
60	21, 27, 41, 58, 78							36				
62	57, 70		63, 101							10, 15, 21	8, 10	19
70							20	12, 15, 21				
75				3, 7, 9, 10, 12	7, 9	10	7		13, 16			
80							7, 12	8, 10	13, 13			
88			8									
89	5, 8		10								4	3, 4, 4, 4
100								6	6, 6, 7			
100-60,[1] 73[2]		7, 9						10, 14	10, 14			

[1] 100° F. from 9 a. m. to 5 p. m.; 60° from 5 p. m. to 9 a. m. [2] Average for 24 hours.

The data at 60° and 62° F. for the laboratory material show a long preoviposition period. (Table 8.) The same material at 88° and 89° and a combination of 100° and 60° show oviposition periods which indicate much speedier development than the temperature increment above 62° would suggest. In common with the time required for the nymphal period, it is evident that at temperatures in the vicinity of 60° and below, the insect's development does not follow the straight-line growth curve (*18, 31*). The results of experiments with hibernants captured in the field late in the fall are interesting when compared with those from the laboratory material in that they indicate either greater vigor on the part of the hibernants or a capacity to develop at lower temperatures than is the case with specimens softened through several generations in a greenhouse. The results at temperatures between 70° and 100° for the late fall hibernants indicate that the ovarian rest period can be broken by high temperatures.

In January, 1928, dissections of females captured in the field showed no signs of development. The results of experiments with these forms suggest the interesting possibility that when the insect has gone through its normal winter rest period it is much more susceptible to temperature effects than before. This is common knowledge in the case of species which undergo true hibernation, but *E. tenellus* does not undergo true hibernation.

One series was run at 75° F. with first-brood material, i. e., fresh females from the progeny of the hibernants, to confirm what has been repeatedly demonstrated by dissection, that when fresh females appear in the field in numbers developed ovaries can be promptly found. All the observations on this point during the four summers have shown that the preoviposition period of the freshly appearing

ATMOMETER CUPS AND PYRHELIOMETER

A, Atmometer cups used in obtaining records of evaporation; B, pyrheliometer used in obtaining records of solar radiation.

females in the spring is very short at the temperatures prevailing normally at that time of the year.

Experiments with hibernants which were kept under various colored glasses were complicated by the fact that the temperatures of the checks could not be kept similar to those of the lighted cages, but these differences in temperature were not of sufficient magnitude to explain the differences in development. There was also some slight opportunity for reflected light to penetrate the wire sides of the check cages. There is evidently great variation between individuals, but the data indicate an acceleration of ovary development in the case where the cage was lighted through Pyrex (clear neutral) glass and Corning G–24 red glass.

The data from a number of experiments on the effects of combinations of light and temperature are summarized in Table 9. From this table it is seen that the results from the checks are not inconsistent with those from females captured in January which were held in the dark for the period of the experiment, and that results from the lighted cages gave, in the case of Pyrex and red glass, indications of an accelerative action of the light.

TABLE 9.—*Summary of experiments on effect of quality of light on preoviposition period of Eutettix tenellus*

Kind of light	Experiment No.	No development in—	Ovaries developed in—	Mature eggs in—
		Days	*Days*	*Days*
Red (Corning G–24, 3.23 mm. thick)	1	10	16, 16, 17	16, 18
	2	7		
	3		9	
	4			14, 16, 20, 22
Pyrex (Corning)	1		10, 16	17
	2	7	11	
	3			9, 10, 11, 11, 11
	4	22	18	14, 22
Blue (Corning "daylight")	1	10	16	
	2			
	3		10	9, 11, 11, 11, 11
	4	14, 22		20, 22, 22
Green (G401CZ, 3.45 mm. thick)	1	10	16	
	2			
	3	9	11	
	4	14, 20		
Check, in darkness	1	10, 17	16	
	2	7	11	
	3	9, 11, 11	11, 11, 11	10, 11, 11
	4	14, 14, 20, 20, 22, 22, 22	22	22, 22
January hibernants, 62° F., in darkness		10, 15, 21	8, 10	19

MINIMUM TEMPERATURES FOR OVIPOSITION

Laboratory-reared adults were placed in a cabinet, in which fluctuating temperatures paralleling outdoor temperatures were available, for periods of four days. At the end of these periods the cages were removed from the cabinet and the insects removed from the plants, which were then left at greenhouse temperatures. Proof that oviposition had occurred in the cabinet was obtained in every case. The temperatures fluctuated between 58° and 31° F. Laboratory and hibernating females were placed in cages under the 500-watt lamp in the basement at temperatures varying from 53° to 58°. In both cases nymphs were obtained, 30 and 37 days later, respectively.

Owing to the fact that the females in both of these experiments were removed from a heated insectary, there is a possibility that oviposition may have been due to a continuation of the activity of the females for a time in spite of the introduction into low temperatures. A somewhat similar indication was obtained from an experiment in the same cabinet at temperatures fluctuating between 64° and 28° F. Nymphs were introduced into the cabinet February 9, 1928, and 24 hours later practically every one had molted. There was no further change until March 17, when adults emerged. This "physiological momentum" is of much interest and some practical significance. If the insects become very active for a short time, as happened later in March, 1928, a sudden drop in temperature does not immediately reduce the insects to inactivity, but may, on the other hand, stimulate molting or oviposition. This unusual activity early in the spring tends to spread oviposition over a longer period than normal.

A series of hibernating adults were caged in the same cabinet during February. Table 10 summarizes the data to April 4. It is seen that while the preoviposition period was completed and oviposition occurred, the temperature accumulations were not sufficient to bring about completion of the egg period. On being removed from the cabinet into a heated insectary, the eggs hatched but not until sufficient time had elapsed to indicate that very little development had taken place in the cabinet. By comparing the temperature accumulations of Table 10 with those for 1926 in Table 6, it will be observed that the totals of 1928 for all three base lines are higher than those of 1926, even when counting the latter to the end of May 3. This is striking evidence of the inadequacy of standard-shade temperature accumulations as indicators, since the first generation of 1926 was emerging by May 3 and the migration followed shortly afterwards.

TABLE 10.—*Temperature accumulations and the incubation of Eutettix tenellus in cages at Twin Falls, Idaho, 1928*

Date	Cage type	Temperature accumulations to Apr. 4 expressed as square inches of surface on the thermograph record between the curve and a given base line			Time required for eggs to hatch after removal to heated room
		Above 40° F.	Above 50° F.	Above 60° F.	
		Sq. in.	*Sq. in.*	*Sq. in.*	*Days*
Feb. 4	Light	37.4	17	4.2	8
	Dark	37.4	17	4.2	8
	do	37.4	17	4.2	12
	do	37.4	17	4.2	12
18	Light	30.7	15.3	4.1	8
	do	30.7	15.3	4.1	10
20	Dark	30.7	15.3	4.1	14
4	do	37.4	17	4.2	15

EFFECTS OF TEMPERATURE ON THE EGG PERIOD

Table 11 records the incubation periods obtained at various temperatures. There is evidently little or no stimulation due to the alternating temperatures used. The optimum temperature is evidently between 80° and 100° F. At temperatures in the upper half

of this range it is probable that the egg, buried as it is in the tissues of the leaf, is not subject to those temperatures constantly. Readings made with a fine thermocouple showed that considerable difference existed between temperatures in the petiole and those in the air immediately surrounding the plant, those in the plant being lower. These differences are not constant, varying from 1° to 5° C. This fact probably accounts for the similarity in length of egg periods between 85° and 100° F.

TABLE 11.—*The incubation period of Eutettix tenellus*

Constant temperature	Eggs from laboratory-reared females	Eggs from hibernant females	Eggs from spring-brood females
° *F.*	*Days*	*Days*	*Days*
55	30	37	
66		31, 48, 31, 29	
70	21		
90–60 [1]	13, 14, 15, 15, 16, 18, 19, 19		
70 [2]			
90–63 [1]	17, 17, 17, 17	12, 14, 14, 16, 16, 17	
72 [2]			
100–60 [1]	12, 22, 22		
73 [2]			
75	11, 12, 12, 12, 12, 12, 13, 13		
80	10, 11, 11	9, 9	
85	7, 7, 7, 7, 8, 9		
90	7, 8, 8	6, 7, 7, 8, 8, 8, 11, 13	6, 6, 7, 7, 8
100	6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 7, 7, 7, 7, 7, 7, 7, 7, 8		

[1] First temperature is for daytime, 9 a. m. to 5 p. m.; second temperature, 5 p. m. to 9 a. m.
[2] Average for 24 hours.

The long incubation period at temperatures of 70° F. and below have some interesting implications when the temperatures of oviposition (see above) are considered. It is evident that oviposition takes place at temperatures which are not favorable for the development of the egg. Should the early spring weather remain cool for some time after the females have developed their ovaries, oviposition would take place, but little development of the eggs would occur until more favorable temperatures have been reached. The effect would be to bring out a large percentage of the first generation at approximately the same time. Should favorable conditions continue, large populations would naturally result. On the other hand, should extremely unfavorable conditions prevail, the species might suffer severe reverses. Such a difference in response to temperature as obtains between oviposition and egg development is an instance of what might be termed biological checks and balances. Normally, for *E. tenellus*, egg development closely follows oviposition, so that by the time the last eggs are laid the nymphs from the first have developed almost to maturity. In this way the critical stages of the life cycle are spread over a comparatively long period.

TIME REQUIRED FOR NYMPHAL STAGES

The data for single instars are charted in Figure 8. The data for the last instar are at the left of the figure; for the other instars, on the right. The last instar, on the average, takes longer than any of

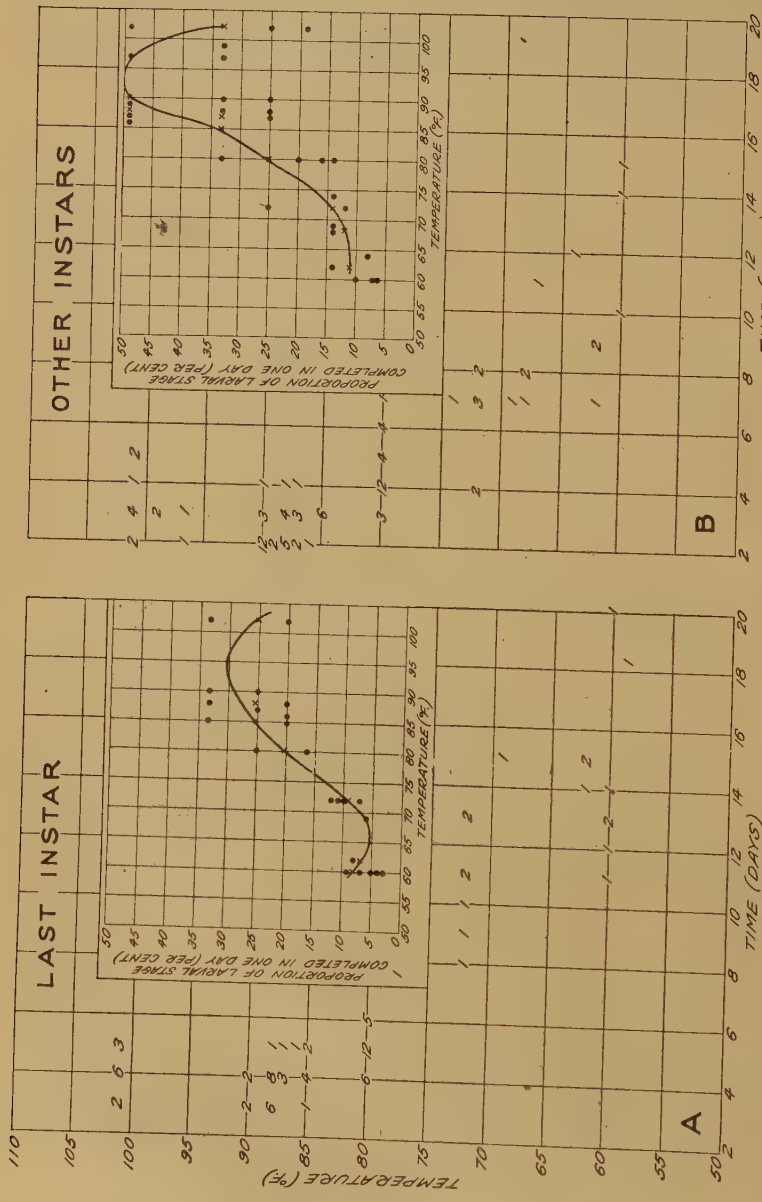


FIGURE 8.—Data relating to length of nymphal stages of *Eutettix tenellus* at different temperatures: A, Time-temperature data and (inset) rate-of-development curve for the last instar; B, data and curve for the other instars

the others. The few cases where exact time was obtained on the first instar suggest that it also is slightly longer than instars in between, but the data are included in the right-hand section of the figure. The insets are the reciprocals. In the plotting of the reciprocals, the points at which the greatest number of cases occurred are indicated by "x." The curve drawn through the points representing the greatest frequencies is the rate-of-development curve. In the case of the last instar a line is obtained which indicates in general the reactions reviewed at some length by Shelford (*31*). At temperatures over 100° F. there is a falling off in the rate, while at 60° F. the relationship again ceases to approximate a straight line. This suggests that factors other than temperature were operating. The data for instars other than the last show a more scattered grouping of the points; the falling off at high temperatures is clear, however.

The data showing the time required to pass through the entire nymphal period are presented in Table 12.

TABLE 12.—*Elapsed time from hatching of eggs to emergence of adults of Eutettix tenellus under varying temperatures*

Constant temperature	Time from hatching to emergence	Constant temperature	Time from hatching to emergence
° *F.*	*Days*	° *F.*	*Days*
65	No completion.	63, 9 a. m. to 5 p. m.	25.
90, 9 a. m. to 5 p. m.	19, 21, 23, 24, 26, 28.	90, 5 p. m. to 9 a. m.	
60, 5 p. m. to 9 a. m.		90	13, 13, 14, 14, 14, 15, 16, 16, 17, 18, 19, 19.
90, 9 a. m. to 5 p. m.	18, 18, 18, 21, 22, 25, 25.		
63, 5 p. m. to 9 a. m.		100	9, 9, 13, 13, 13, 13, 14, 14, 15, 15, 15, 15, 17, 17.
80	22, 23, 24, 25.		

CLIMATE-SIMULATION EXPERIMENTS

The reactions of insects to constant temperatures are interesting physiologically, but it is extremely difficult, if not impossible, to translate these data in terms of the temperatures encountered in the field. Shelford (*31*) records data obtained through climate-simulation experiments. An attempt has been made in this study to initiate similar experiments. A Carrier cabinet was so arranged that outside air was blown in at the lower pair of intakes and exhausted from the upper pair. Light was provided by means of a 500-watt lamp hung in the cabinet. Cages were so constructed as to permit almost full intensity of the light to pass through. The results of these experiments are listed in Table 13 and the hygrothermograph record for one week is shown in Figure 4, C. Plate 4, A, shows the types of light cages used. The celluloid cage at the right was placed over a young beet in a pot. Plate 4, B, shows field cages in which electric-resistance thermometers were placed for recording the temperatures obtained. The conditions obtained in the climate-simulation study were closer to soil-surface conditions than were those of the standard shade (fig. 4), but considerable modification will be necessary before the experimental conditions can be considered similar to those to which the insect is subjected.

TABLE 13.—*Duration of egg and nymphal periods of Eutettix tenellus and accumulated temperatures from climate-simulation experiments*

Stage	Length of period	Accumulated temperatures expressed as square inches of surface on the thermograph record between the curve and a given base line			
		Above 40° F.	Above 50° F.	Above 60° F.	Above 70° F.
	Days	*Sq. in.*	*Sq. in.*	*Sq. in.*	*Sq. in.*
Egg period	17	23.9	15.6	8.63	4.50
	13	19.3	12.8	7.40	4.18
	20	29.6	18.6	10.80	6.14
	13	22.8	15.5	8.30	6.41
	12	20.9	14.5	9.25	5.11
	12	21.3	14.6	10.50	5.62
	11	18.2	12.3	7.41	3.93
	14	22.9	17.5	9.09	4.81
	12	21.1	14.5	9.25	5.11
	13	22.8	15.5	9.72	5.81
	11	18.2	12.3	6.71	3.93
	11	19.2	13.5	7.75	4.75
	13	22.7	14.9	9.82	5.61
	10	17.1	11.0	7.25	4.22
	11	19.2	13.5	7.75	4.75
	14	24.6	17.2	10.80	6.08
Average	12.94	21.49	14.61	8.78	5.06
Total nymphal period	27	40.9	25.6	15.0	7.88
	20	35.6	25.7	15.9	9.23
	21	36.0	24.6	15.5	9.20
	22	37.6	25.7	16.1	9.53
	21	37.6	26.7	16.6	9.23
	22	37.6	24.6	16.1	9.34
	20	36.0	24.6	15.5	1.20
	20	36.0	24.6	15.5	1.20
	22	37.6	24.6	16.1	9.34
	30	52.5	36.9	24.4	13.30
	23	39.5	27.7	17.1	9.78
	20	34.4	22.8	17.3	8.48
	21	35.8	23.6	17.7	8.75
	21	36.6	26.2	16.2	9.63
	22	38.2	27.4	16.8	9.95
	20	35.2	25.3	15.7	9.39
	22	37.1	26.0	16.0	9.05
	22	37.1	26.0	16.0	9.05
Average	22	37.85	26.03	16.64	8.53

With the diurnal fluctuations obtained the time for the egg period and the nymphal stages is approximately equal to the time required for these same stages at 75° F. constant temperature. Planimeter measurements of the space on the thermograph record, between the temperature curve and a given base line, for one day at a constant temperature of 75° F. are as follows: Above 40°, 1.74 square inches; above 50°, 1.27 square inches; above 60°, 0.73 square inch; above 70° 0.26 square inch.

For the average egg period at 75° F., 12 days, the totals accumulated are 20.88, 15.24, 8.76, and 3.12 square inches, respectively. At the fluctuating temperatures used, with an average egg period of 12.9 days, the accumulations are 21.49, 14.61, 8.78, and 5.06 square inches, respectively.

For the average time for the total nymphal period, 22 days, the accumulations at 75° F. are 38.28, 27.94, 16.06, and 5.72 square inches, with corresponding totals for the fluctuating temperatures of 37.85, 26.03, 16.64 and 8.53 square inches, respectively.

The thermograph curve for the fluctuating-temperature experiment was within the limits of the straight-line portion of the rate-of-devel-

opment curve, with rare exceptions of short duration, but the close agreement between the totals accumulated at a constant temperature and those at fluctuating temperatures is significant.

EFFECT OF HUMIDITY

It is doubtful whether humidity is ever a limiting factor under normal field conditions in southern Idaho. Field observations show a decided preference on the part of the insect for situations which are more open and have lower humidities, but since these conditions are also associated with higher temperatures, the relative importance of humidity as a factor in the preference is difficult to determine. Under laboratory conditions, nymphs were killed in saturated atmospheres at temperatures between 60° and 85° F. in darkness. At temperatures from 50° to 60° at approximately 70 per cent relative humidity in the dark, nymphs were unable to complete their life cycle but lived for months. Severin (*27*) reports that on one occasion nymphs were killed in the field by 0.47 inch of rain but does not go into detail as to the circumstances. The months of April and May, 1927, were extremely wet for this area, but populations of *E. tenellus* were high shortly afterwards, nevertheless. There have been no indications thus far that humidities in the field are significant except in so far as they may condition the insect's preference in local situations. This may not hold true in other areas, particularly in such places as the fog belt of California.

There are some indications that humidity is a factor in the deposition of dark coloring matter in the wings. Dark forms normally appear in the fall, but they are also frequent in laboratory and greenhouse colonies which are kept in poorly ventilated cages in which the humidity is high. At temperatures just above 60° F. and under conditions of high humidity, no typically light cream-green "summer" form has ever been produced during the course of these investigations.

EFFECT OF WIND MOVEMENT

Normally *E. tenellus* seeks protection from wind. During the warm days of the winter of 1927–28, when the overwintering populations were large, a slight breeze was sufficient to drive the insects to cover in the cracks in the soil or under débris. When settled down on a plant the insect is able to resist considerable air movement; a domestic vacuum cleaner run over the surface of a beet leaf failed to dislodge the insects and the only specimens caught were those disturbed into flight. When disturbed the insect seems to be extremely susceptible to air movement and the incidence of high winds in the spring of the year is probably of some importance to the direction of migration.

EFFECT OF LIGHT

In 1927 one beet field of 17 acres was plowed up except for two rows in the middle. This afforded an excellent opportunity for a study of light reactions, since these two rows had an enormous concentration of leaf hoppers on them and there was bare ground for a considerable distance on two sides, a road on another side, and another crop on the fourth. Traps were arranged consisting essentially of a Mazda lamp over a pan of water covered with a thin film of oil. A 75-watt lamp brought an occasional *tenellus* to the trap when the trap was placed

at a distance of 6 feet from the rows. At 3 feet the response was better. Nymphs appeared to be equally as phototropic as adults. The overnight catch was insignificant, however. Two traps were then fitted with 200-watt clear Mazda lamps, one trap being set 40 feet from the nearest row and the other 4 feet. There was considerable breeze. The next day 427 *tenellus* were removed from the trap at 4 feet and 42 from the one at 40 feet. There was no apparent dimunition of the numbers of *tenellus* left on the plants. The result does indicate, however, a definite relationship between light intensity and phototropism.

INTERRELATIONSHIPS BETWEEN EUTETTIX TENELLUS AND ITS HOST PLANTS

The relationships between *E. tenellus* and its host plants are of fundamental importance. The remarkable migrations of the insect into beet fields are of challenging interest to the entomologist and of grave import to the beet-sugar industry. The study in the field has been centered on the relationships between insect and host on the hypothesis that there was the most likely source of information on the cause of migration, the factors affecting abundance, and the possible cyclic nature of this abundance. Frequent reference will be made to the data on the physical factors of the environment, since correlations between these and the insect's activity are in some instances reasonably clear.

The economic problem of curly top in the Snake River Valley, if present conditions are sufficient indication, has been brought about by the introduction of certain host plants which have proved favorable for the development of large populations of *E. tenellus*. The years of high wheat prices stimulated the breaking up and cultivation of large areas of semiarid land close to the irrigated tract. With the collapse of high prices these lands proved to be submarginal and were abandoned. (Pl. 1, C.) Water shortage led to the abandonment of large acreages of land which were originally cleared of sagebrush with the intention of irrigating them. On most of these abandoned lands the prevailing plants are hosts for *E. tenellus*. A large number of other hosts are listed by Haegele (*19*).

Table 14 presents a summary of the seasonal development of six of the principal host plants in the area for which Twin Falls is the center. These plants are *Sophia sophia* (L.) Britton, flixweed or herb-sophia; *Sophia filipes* (Gray) Holler, a species of mustard; *Sisymbrium altissimum* L., Jim Hill mustard; *Salsola pestifer* A. Nels., Russian thistle; *Atriplex rosea* L., red orache; and *Solanum triflorum* Nutt., cut-leaved nightshade.

LABORATORY AND FIELD CAGES

A, Cages used in studies of the effect of light on the development of *Eutettix tenellus;* B, field cage with electric-resistance thermometers inserted.

STAGES IN GROWTH OF ATRIPLEX ROSEA

A, Dense growth of *A. rosea* in a moist situation; B, dense growth of *A. rosea* which has thinned out as the season progressed.

TABLE 14.—*Seasonal development of some common annual host plants of Eutettix tenellus in the Twin Falls, Idaho, district*

Host plant	Time of germination	Early growth form	Early summer	Midsummer	Late summer	Fall
Sophia sophia	Fall	Leaves, erect stems	Early maturity, leaves remaining succulent some time after seed pods are formed.	Matured and drie up		Dead.[1]
Sophia filipes	do	do	Very early maturity involving complete drying up of entire plant.	do		Do.[1]
Sisymbrium altissimum	do	Flat rosette of leaves	Early maturity associated with drying up of basal leaves.	do		Do.[1]
Salsola pestifer	Fall, spring, and summer.	Tufts of grass-like leaves.	Many growth forms [1]	Great variation from young succulent forms to partly mature growth of high sap concentration.	Mature. High sap concentration.	Do.[1]
Atriplex rosea	Spring	"Buttons" of thick leathery leaves.	do.[1]	High sap concentration common.	Life cycle completed	Do.[1]
Solanum triflorum			Recumbent plants often 36 inches across.		Leaves shedding. Plant less dense.	Do.[1]

[1] See discussion in text.

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DISCUSSION OF THE COMMON ANNUALS

The three species of mustard, *Sisymbrium altissimum*, *Sophia sophia*, and *S. filipes*, grow wherever land has been abandoned after cultivation. The large area involved and the rapid growth and early maturity of the plants constitute a real menace, since the insect populations must move on sooner or later in the early summer. The factors governing the suitability of these three species as hosts are difficult to determine. Two possible ones for consideration are cell-sap concentration and maturity, the latter involving hardness of the tissue and changes in the chemical constitution of the plant. None of these hosts are xerophytic, and maturity comes before the concentration of the cell sap has reached points previously shown to be unfavorable (*6*). The maturity of these plants, however, involves hardening of the tissues and loss of succulence, i. e., of sap available. *E. tenellus* is known to oviposit more freely on tender plants than on older, harder specimens. The measuring of hardness of tissue has not been attempted, but the hypothesis that it is a factor is tenable. Maturity also involves chemical changes which might well be concerned in the insect's economy, but no attempt has been made as yet to measure them.

With the growth and maturity of the mustards, other hosts appear. *Atriplex rosea* and *Salsola pestifer* are both comparable in importance to the mustards as hosts of *E. tenellus*. *A. rosea* is slow to germinate but is in favorable condition when the mustards perish. It is widely scattered over abandoned lands and is remarkable for its many growth forms. These have an important bearing on the suitability of this species as a host for the insect. On shallow or gravelly soil, distant from irrigation ditches and dependent on the scant natural precipitation, the plant is of short growth with comparatively small leaves. In seepage areas, and on old feed lots where moisture-holding humus is present, the plant grows tall with large leaves, and often so dense as to make progress through it difficult. Between these two extremes are many intermediate grades, and in some locations the dense large-leaved form thins out as the season progresses. (Pl. 5.)

Salsola pestifer also presents interesting growth forms. The germination of this plant is irregular. Late fall germination occurs, but, as has been mentioned, these plants do not appear to survive the winter if it is severe. Areas are to be found on which the plant appears to have germinated at intervals during the summer so that forms varying from mature, prickly, bushy plants, to short and very succulent ones are to be found. Occasionally the plants wither while in bloom, but this form should not be confused with that which has attained a high sap concentration along with normal growth.

These two species, *Atriplex rosea* and *Salsola pestifer*, offer an opportunity to test the validity of the hypothesis that cell-sap concentration is of importance. Both species of plant are xerophytic in habit, both attain high sap concentration, and both are often found growing in close proximity to each other. The writer has already published a paper on this question (*6*). Additional data are presented in Table 15. Still more data along the same lines are tabulated under the heading "Quantitative data from desert observation stations."

TABLE 15.—*Growth form and depression of cell-sap freezing point of host plants of Eutettix tenellus associated with populations of the insect, Twin Falls, Idaho*

Host	Growth form	Depression of cell-sap freezing point	E. tenellus collected per 100 sweeps of net				Probable factor influencing leafhopper populations
			Males	Females	Nymphs	Total	
		° C.	*Number*	*Number*	*Number*	*Number*	
Atriplex rosea	"Dry" short	5.00				13	Sap concentration.
Do	Transitional	2.73				95	Growth form.
Do	Rank, dense	2.4				65	
Do		5.25	128	40	26	194	Sap concentration.
Salsola pestifer		.63	286	266	120	672	
Atriplex rosea	Rank	3.67	40	14	0	54	Growth form.
Salsola pestifer	Short	3.25	126	121	75	322	
Atriplex rosea	Transitional	5.00	44	18	10	72	Sap concentration.
Salsola pestifer	do	2.90	338	162	16	516	
Solanum triflorum	do	2.45	318	174	2	494	
Atriplex rosea	Rank, dense	1.93	26	6	2	34	Growth form.
Salsola pestifer		2.80	12	10	6	28	
Do	Withered	3.25	2	14	0	16	Sap concentration.
Do	Short, succulent	2.55	4	26	2	32	
Do	Dense	2.60	90	368	11	469	Growth form.
Do	Sparse	1.95	532	800	32	1,364	
Atriplex rosea	Dense, rank	3.06	0	12	1	13	Growth form and sap concentration.
Do	Transitional	5.90	26	54	8	88	
Salsola pestifer		3.50	148	202	70	420	
Atriplex rosea	Dense, rank	3.06	0	5	0	5	Growth form.
Do	Transitional	4.49	10	59	5	74	
Do	Dense, rank	3.47	2	4	0	6	
Do	Transitional, dry	5.00	4	12	0	16	Do.
Sisymbrium altissimum		1.89	19	50	0	69	

As to the relative importance of growth form and sap concentration, experience indicates that the rank, dense growth is unfavorable as an environment for *E. tenellus*. This is particularly true in the case of *Atriplex rosea*. Large populations of the insect thus far have never been found on such *A. rosea* growth. The predominant insect on *A. rosea* is a small pale-green mirid, *Atmoscelis modestus* Van D. This predominance is lost to *E. tenellus* on plants of *A. rosea* which are in sparse growth, but where the plants grow rank and dense the mirid continues predominant. Counts of the mirid are difficult to make since the insects are present in such quantity as to form a crushed mass in the net. Quantitative collections from dense and sparse *Salsola pestifer* invariably show much heavier leaf-hopper populations on the sparser growth, with which are associated higher temperatures, lower humidity, and less shade. Where other conditions are equal, however, it can be said that between *A. rosea* and *S. pestifer* the deciding factor which influences leaf-hopper populations is cell-sap concentration.

The obvious preference of *E. tenellus* for environments that are not shaded can normally be explained on the basis of the physical conditions of the external environment.

THE RÔLE OF THE PERENNIAL HOST PLANTS

Greasewood (*Sarcobatus vermiculatus* Torr.) has been mentioned as a host plant (*1*, *19*, *22*). The data of Table 16 indicate that as far as succulence and cell-sap concentration are concerned, *S. vermiculatus* is favorable for a prolonged period. *Grayia spinosa*, on the other hand, develops high sap concentration and sheds its leaves early in the season. These facts alone would preclude it as a favorable

host. On only one occasion was *E. tenellus* taken from this species and only two specimens collected at that time. Occasional collections from greasewood do yield *E. tenellus*. Why this plant is not more favorable is a moot question, but the fact is that the large populations have not been encountered on that host. One exception to this is noted below. The probability is that perennial plants were the principal hosts of the insect before the advent of the now widely scattered introductions, but through natural balance the predominance of *E. tenellus* has been prevented. The number of spiders to be found on greasewood is remarkable. A combination of circumstances might, however, force the perennial plants which are green in the fall to assume another rôle.

TABLE 16.—*Data from observations on a mixed stand of Sarcobatus vermiculatus and Grayia spinosa at Twin Falls, Idaho*

Week ended	Depression of cell-sap freezing point of—		Soil moisture at [1]—		
	Sarcobatus vermiculatus	Grayia spinosa	6 to 12 inches	19 to 24 inches	30 to 36 inches
1925	° C.	° C.	*Per cent*	*Per cent*	*Per cent*
May 21	2.56	2.49			
June 15	2.62	3.845			
22	2.65	3.76	9.5	12.5	17
29	2.74	4.62	2.4	16.6	17.9
July 6	2.77	5.01	12.6	17.2	17.2
13	2.74	5.30	12.6	15.5	17.0
20	3.33		9.6	15.7	17.5
27	3.18		9.8	15.3	17.0
Aug. 3	2.76		17.6	17.42	17.6
10	2.59		16.3	19.7	20.6
17	3.18		10.9	16.8	20.0
24	[2].65		11.0	18.2	17.9
31	3.26		10.8	19.2	19.2

[1] Water-holding capacity, 54 per cent. Salts (electric bridge), 300 parts per 1,000,000.
[2] Sap on this date was enormous in quantity.

The summer of 1927 was a dry one, and with little interruption the drought continued until the last few days of October. Previous to the rain, the temperatures were abnormally high. *Salsola pestifer*, which normally supports the insect until the fall germination of the mustards takes place, dried up completely and the insect was forced to seek food elsewhere. For the first time *E. tenellus* was found on rabbit brush (Chrysothamnus). No quantitative collections were made, but over 200 specimens were captured in a few hours. This plant was growing alongside a stand of *S. pestifer* which at that time was yielding only a small fraction of *tenellus* populations obtained from there two weeks earlier. The insect had obviously been driven off the *S. pestifer* and had found refuge upon the first green food encountered. A few days later this same condition was found to hold over the entire area from Twin Falls westward. Wherever greasewood or rabbit brush was close to old *S. pestifer* stands, the insect was found on the perennials. In a few places the mustards had germinated and there the insect was predominantly on the fresh growth. The possible effect of this movement to unusual hosts is discussed further in connection with the hibernation of the insect.

The spring distribution of the insect at the Castleford desert station suggested strongly that hibernation had been accomplished in contiguous sage brush (Artemisia).

OCCASIONAL HOSTS

Many occasional host plants have been encountered, but large populations of *E. tenellus* on these are rare. The only positive collection ever made on *Cleome lutea* Hook., however, yielded a very considerable population (123 males, 367 females, and 22 nymphs). Such a population suggests an intercepted migration or a movement from near-by hosts which had become unfavorable.

HOST-PLANT SUCCESSION THROUGHOUT THE SEASON AND THE RELATIVE IMPORTANCE OF THE MUSTARDS AND RUSSIAN THISTLE

Although the relations between *E. tenellus* and specific host plants are important, the true picture of the insect's desert activities can be seen only through a consideration of the succession of host plants throughout the season.[6] Beginning with early spring, the insect is found on the mustards. These are short-lived plants, growing with extreme rapidity and maturing in the early summer. In spite of the intense competition between *E. tenellus* and other insects, large populations of the former develop on these plants before their maturity. In the meantime other hosts, principally *A. rosea* and *S. pestifer*, have become available. The *tenellus* populations on *pestifer* become very high during the course of the season, particularly where the growth is sparse. The populations on *rosea* are materially affected by the growth form of the plant, but in any case *A. rosea* matures and dies in the late summer, leaving *S. pestifer* the sole surviving member of the succession. Exceptions to this occur, of course, owing to local conditions. *Solanum triflorum* sometimes carries *E. tenellus* over until the cold weather starts. The rôle of the perennial plants in this connection has been discussed previously. The late fall rains germinate the mustards, and the insect then leaves either the *S. pestifer* or the perennials and can be found on the freshly germinated mustards throughout the winter. It frequently happens that the freshly germinated mustards can be found underneath old *S. pestifer* plants, so that the insect can thus find food as well as shelter at the same time.

The quantitative-collection data from the desert observation stations indicate clearly that the highest populations of the insect are encountered on *S. pestifer*. Several possible explanations for this are available: One is that *pestifer* is favorable from the beginning of the season to the end, whereas the mustards are all short lived; another is that the environment offered by *S. pestifer* in sparse growth is more favorable to the rapid development of *E. tenellus* because of more favorable physical factors of the environment; while a third is that competition is much more severe on the mustards than it is on *pestifer*, as reference to the data in Table 21 shows. A large number of other insect species snatch the brief opportunity afforded them by the growth of the mustards, and but few of these pass over to *S. pestifer*, even though the latter is growing in close proximity. In

[6] This study covered only one area—that of central-southern Idaho. Specific hosts as well as host-plant successions vary widely within the limits of the insect's range.

view of the wide variation in populations encountered on the mustards, it is very unlikely that the factor of competition enters in until the peaks of population are reached. The data presented in Table 17 and Figure 9 demonstrate that *E. tenellus* will on occasion remain on *Sophia sophia* until the plant dies in spite of unfavorable sap concentration and maturing plant tissues.

With regard to the physical factors of the environment, the data in Table 3 show the differences in temperatures at the soil surface, 6 inches above the surface, and 27 inches above the surface. This table shows that the higher temperatures prevail at the lower levels. Since, in the case of the mustards, the principal feeding area is 2 feet or more from the ground, except for a very short time in the spring, the data indicate that temperatures are more favorable to *tenellus* living on *pestifer* than on plants whose feeding area is farther removed from the added temperature due to reflection from the soil. When *S. pestifer* is in dense growth, populations of *tenellus* decrease, but this may be due as much to decreased light and higher humidities as to lowered temperatures. The charts showing hygrothermograph data referred to previously (fig. 2) indicate the high temperatures and low mean humidities prevailing in a typical stand of sparse growth of *S. pestifer*. All the experience in the field supports the view that low humidities are preferred; and the data on the effect of temperature on the insect show the remarkable speed of development of the insect at high temperature; so that it can safely be stated that a sparse growth of *S. pestifer* represents the environment most nearly optimum for *E. tenellus* thus far encountered.

When the sequence of host plants is considered and the temperature data for an area which contained three of the principal host plants are referred to (Table 4), it will be seen that favorable temperatures for the rapid development of the insect are available for a much longer time than the usual weather data would indicate. Within a short vertical range of less than 3 feet temperatures vary from below to far above the optimum. Under such conditions what will the reaction of the insect be to these variations? Does it seek the optimum conditions available within its immediate environment? With an active insect, such as *E. tenellus*, it is extremely probable that such is the case. Such a reaction has been demonstrated for other insects living in a comparable environment (*10*). The concept is important, if environmental data are being used as a means of predicting the end of a phase in an insect's life cycle. In support of the view that *tenellus* acts in the way described, it may be remarked that the highest populations are always to be found in places where theoretically optimum physical conditions exist, and that this is a matter of preference seems to be established when comparisons are made within restricted environments a few feet apart. An insect may not be predominant even if its environment be nearly optimum, since its competitors may also find their optimum under the same conditions. If a species is predominant to such an extent that it is predominant over all other species combined, then the environment may be considered as a practical optimum for the species. Since temperature conditions in any environment for *E. tenellus* thus far considered are never uniformly optimum throughout the environment, the probability is that the insect must seek the best available in order to command the predominance which it undoubtedly does on *S. pestifer* in sparse growth.

DATA FROM WEEKLY OBSERVATIONS AT TWO DESERT STATIONS IN 1926

Tables 17 and 18 and Figures 9 and 10 present data obtained at Adelaide, Idaho, in 1926. The two stations were approximately 1 mile apart and were both situated on old abandoned farms. Observations were started early in April, and large numbers of *E. tenellus* could be captured without difficulty on April 10. On that date, with a free-air temperature of 68° F., the temperature on a small *Sisymbrium altissimum* rosette was 86°. Second and third instar nymphs were common on April 26, and a temperature of 111° was registered on the soil surface, with an air temperature of 74°. Vege-

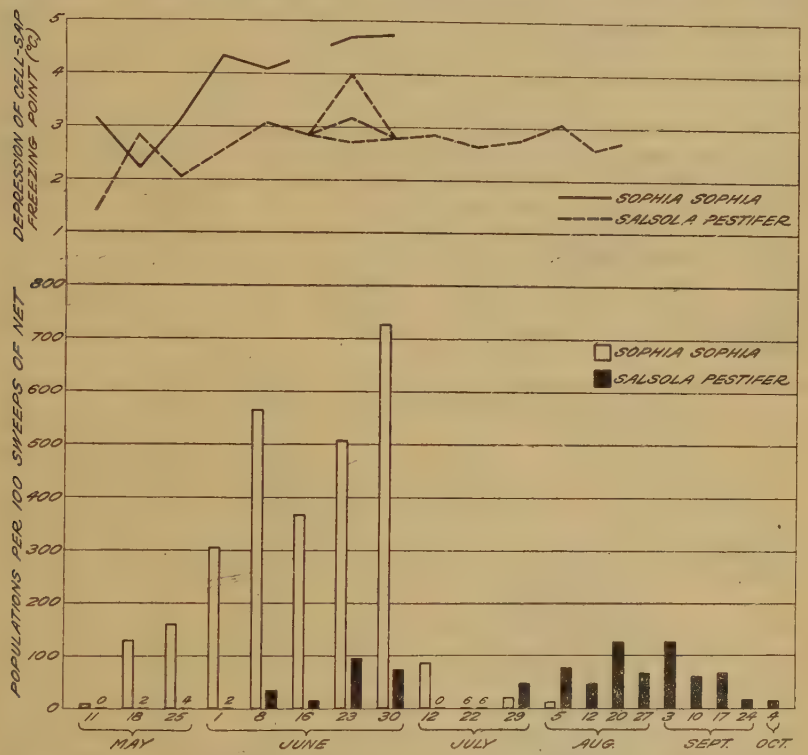


FIGURE 9.—Data on cell-sap concentration and number of *Eutettix tenellus* collected from host plants in the Adelaide, Idaho, observation station, 1926

tation was short and somewhat scattered, and quantitative sweepings were not begun until May 11. Prior to this time, however, adults of the first generation were in evidence, and by May 11 the desert breeding grounds west of Twin Falls had dried up and the migration into the beet fields taken place. At the Adelaide stations, at a much higher altitude, the insect's development was behind that at places farther west, and, owing to heavy local showers the host plants at these stations continued to survive.

In Table 17 and Figure 9 only two host plants are considered, *Sophia sophia* and *Salsola pestifer*. The insect had been observed on the *sophia* in the fall of 1925, at which time the plants were about 2 inches in height. The winter was mild, and these plants continued

to provide food for the insect throughout the entire winter. On June 30, 1926, on *sophia* the progeny of the first brood had developed in great numbers. Reference to Table 17 will show the great preponderance of nymphs on *S. sophia*. But *S. sophia* was practically dead on July 12, and only the few *tenellus* that could find sustenance on the almost brittle stems remained at that time. Since this crisis in the insect's economy came at a time when the population was composed largely of nymphs, the importance of hot, dry weather in cutting off entire populations of the insect can be readily appreciated. Close to the *S. sophia* was an extremely dense stand of *S. pestifer*, growing in the abandoned farmyard. Enormous numbers of false chinch bugs were found on it, literally covering the foliage. The chart indicates, however, two leaf-hopper population peaks in this plant, brought about by a short second generation, no doubt starting from first-generation individuals which were driven from the *sophia* growing in close proximity to the *pestifer*, and a third generation, representing the normal development of the initial population. The cell-sap data indicate the protected condition of the *S. pestifer*, growing as it was on the old humus accumulations of the farmyard, since the sap concentration remained practically constant throughout the season. That of *S. sophia*, however, rose to unusual heights, since normally the short-lived annuals perish before the concentration of their cell sap has produced a depression of the freezing point of 3° C.

TABLE 17.—*Cell-sap concentration and number of Eutettix tenellus taken from host plants at the Adelaide, Idaho, observation station*

Date	Host plant	Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net		
			Males	Females	Nymphs
1926		°C.			
May 11	Sophia sophia	3.18	0	2	8
	Salsola pestifer	1.41	0	0	0
18	Sophia sophia	2.20	34	22	74
	Salsola pestifer	2.85	2	0	0
25	Sophia sophia	3.10	70	60	28
	Salsola pestifer	2.075	0	4	0
June 1	Sophia sophia	4.37	76	116	114
	Salsola pestifer	2.53	0	2	0
8	Sophia sophia	4.10	212	194	158
	Salsola pestifer	3.10	20	12	2
16	Sophia sophia	(1)	140	148	78
	Salsola pestifer	2.83	4	8	0
23	Sophia sophia	4.70	176	128	202
	Salsola pestifer	2.70			
	Salsola pestifer (rank)	3.20	24	66	6
	Salsola pestifer (dry)	4	12	2	0
30	Sophia sophia	4.75	124	32	572
	Salsola pestifer				
	Salsola pestifer (rank)	2.8	32	42	0
	Salsola pestifer (dry)		4	8	4
July 12	Sophia sophia		18	14	56
	Salsola pestifer	2.85	0	0	0
22 [2]	Sophia sophia		0	2	4
	Salsola pestifer	2.65	4	2	0
29	Sophia sophia		4	2	12
	Salsola pestifer	2.76	6	20	22
Aug. 5	Sophia sophia		4	0	8
	Salsola pestifer	3.03	42	20	14
12	Salsola pestifer	2.59	12	18	16
20	do	2.71	62	34	32
27	do		42	20	6
Sept. 3	do		78	46	2
10 [2]	do		36	10	14
17	do		38	28	0
24 [3]	do		14	2	0
Oct. 4	do		8	4	0

[1] Sample of sap was lost; it was very small in quantity and thick. [2] Windy. [3] Cold.

In Table 18 and Figure 10 *Sisymbrium altissimum*, *Sophia sophia*, and *Salsola pestifer* are the hosts concerned. *E. tenellus* was found on *sophia* until the 23d and on *altissimum* until the 29th of July. By this time *S. pestifer* had grown sufficiently to permit of a quantitative sweeping. At this station the *S. altissimum* began to dry up very early (pl. 6, A), but since this drying out was very uneven, collections were taken from the most succulent as well as from the drier, almost mature plants. From Figure 10 it is evident that until the end of the first week in June *E. tenellus* developed more quickly on the more

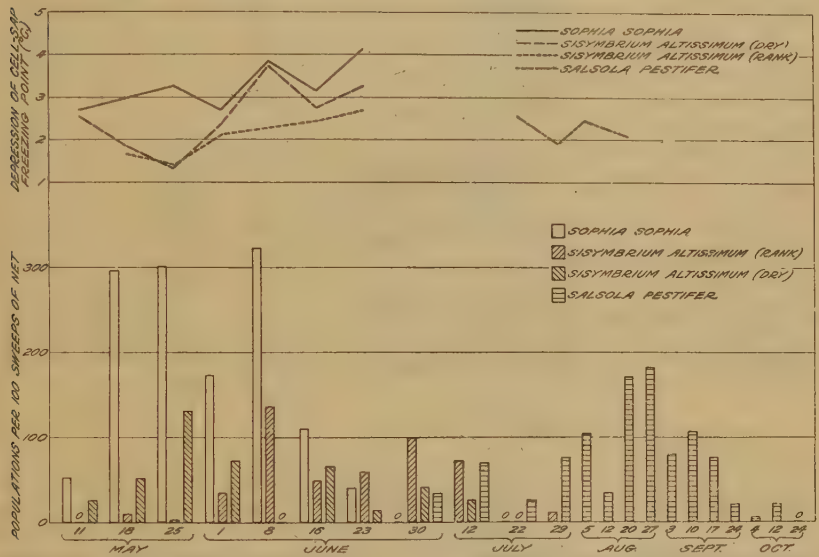


FIGURE 10.—Data on cell-sap concentration and number of *Eutettix tenellus* collected from host plants in a desert observation station at Adelaide, Idaho, 1926. (*Sophia sophia* was dried up on June 30, *Sisymbrium altissimum* was dried up on July 22, and *Salsola pestifer* yielded no insects on October 24)

open, drier *altissimum* growth. By that time all the *altissimum* was rapidly maturing and the distinction between the two types was maintained with difficulty. The data show that much greater populations could be found on *S. sophia* than on *S. altissimum*. The growth forms of the two mustards are very much alike, so that differences in population are probably not associated with the physical environment but are due to the fact that *S. sophia* in the preceding fall was more favorable for the insect and initial populations were therefore higher. At this station the peak of population was reached earlier than at the other station, but the sudden drop in numbers of nymphs without a corresponding increase in adult numbers suggests that the host plants were rapidly becoming unfavorable.

TABLE 18.—*Data from a desert observation station at Adelaide, Idaho, relating to soil moisture, cell-sap concentration, and number of Eutettix tenellus taken from host plants, 1926*

Date	Soil moisture			Host plant	Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net		
	0 to 6 inches	6 to 12 inches	18 to 24 inches			Males	Females	Nymphs
1926	*Per cent*	*Per cent*	*Per cent*		° *C.*			
Apr. 10	11.85	12.52	7.58	Sophia sophia	1.5	(1)	(1)	(1)
				Sisymbrium altissimum	1.6	(1)	(1)	(1)
21				Sophia sophia	1.95	(1)	(1)	(1)
				Sisymbrium altissimum	1.7	(1)	(1)	(1)
26	7.6	8.34	8.21	Sophia sophia	2.6	(2)	(2)	(2)
				Sisymbrium altissimum	1.8	(2)	(2)	(2)
May 4	5.33	7.17	8.10	Sophia sophia	3.50	(2)	(2)	(2)
				Sisymbrium altissimum	1.85	(2)	(2)	(2)
				Sophia sophia	2.70	6	10	36
11	4.91	7.57	8.66	Sisymbrium altissimum—				
				Rank		0	0	0
				Dry	2.54	2	6	18
				Sophia sophia	2.95	86	76	134
18	4.72	7.37	7.01	Sisymbrium altissimum—				
				Rank	1.69	10	0	0
				Dry	1.85	14	4	34
				Sophia sophia	3.25	144	86	70
25	4.13	7.10	7.41	Sisymbrium altissimum—				
				Rank	1.395	2	0	2
				Dry	1.35	54	44	32
				Sophia sophia	2.70	56	82	34
June 1	2.87	6.20	6.46	Sisymbrium altissimum—				
				Rank	2.10	8	18	8
				Dry	2.35	20	36	16
				Sophia sophia	3.84	96	54	172
8	3.71	5.81	8.36	Sisymbrium altissimum—				
				Rank	2.28	64	66	6
				Dry	3.73	0	0	0
				Sophia sophia	3.15	52	22	36
16	3.57	6.13	7.27	Sisymbrium altissimum—				
				Rank	2.43	24	20	4
				Dry	2.75	40	18	6
				Sophia sophia	4.13	18	2	18
23	2.48	3.82	5.94	Sisymbrium altissimum—				
				Rank	2.70	34	8	16
				Dry	3.29	12	2	0
				Sisymbrium altissimum—				
30	1.71	7.94	6.21	Rank		26	2	70
				Dry		14	2	26
				Salsola pestifer		26	6	2
				Sisymbrium altissimum—				
July 12	4.76	5.63	7.09	Rank		14	2	56
				Dry		10	2	14
				Salsola pestifer		30	18	20
22	3.54	5.12	6.93	Sisymbrium altissimum		0	0	0
				Salsola pestifer	2.55	2	18	4
				Sisymbrium altissimum—				
29	2.73	4.62	6.22	Rank		0	2	8
				Dry		0	0	0
				Salsola pestifer	1.85	34	26	16
Aug. 5	2.22	3.94	6.09	do	2.44	22	52	28
12	2.49	4.53	6.98	do	2.26	14	14	6
20	3.05	5.95	7.44	do	2.11	90	48	32
27	2.52	5.03	7.53	do		112	38	32
Sept. 3	3.23	6.0	8.10	do		52	16	12
10	2.91	5.30	8.32	do		54	18	34
17	2.60	4.83	6.74	do		40	28	4
24	3.35	5.28	8.33	do		16	4	0
Oct. 4				do		4	0	0
12				do		6	14	0
24				do		0	0	0

[1] *E. tenellus* very plentiful on vegetation too short to sweep. [2] Nymphs common.

DATA FROM DESERT OBSERVATION STATIONS

Data relating to desert environment and leaf-hopper populations, obtained from desert observation stations in 1927, are presented in Table 19. Physical data obtained from soil samples from six of the desert stations are given in Table 20. Figure 11 shows the approximate area represented by the stations and Figure 12 shows the comparative areas occupied by specific host plants.

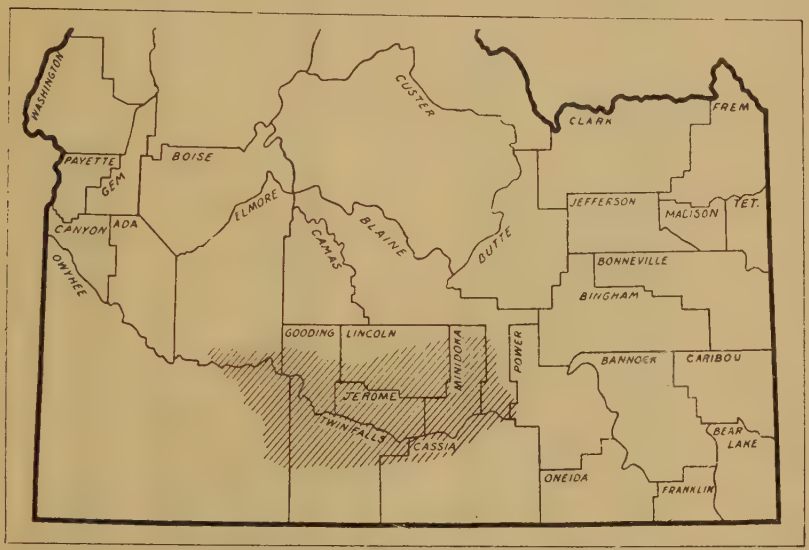


FIGURE 11.—Approximate area (shown by shading) covered by the desert observation stations operated in the Twin Falls, Idaho, district during 1927

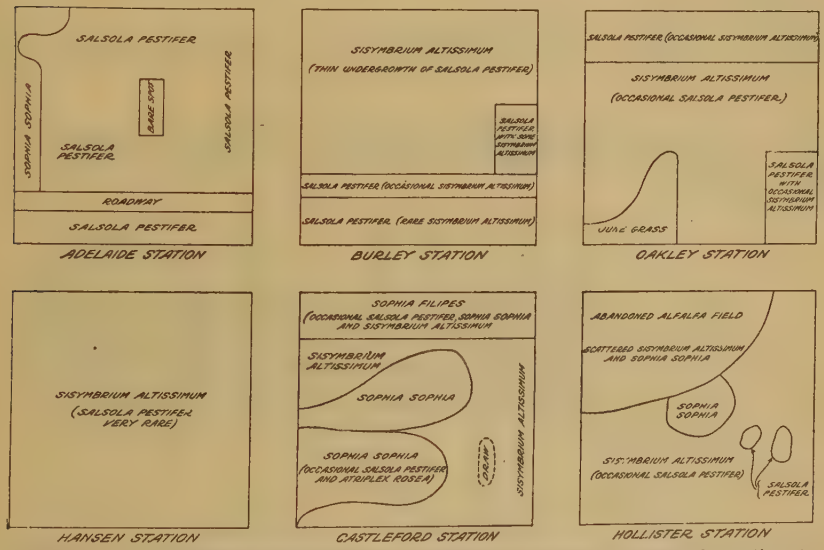


FIGURE 12.—The comparative areas occupied by specific host plants at the desert observation stations operated in the Twin Falls, Idaho, district during 1927

TABLE 19.—*Data from the Adelaide, Oakley, Burley, Hansen, Hollister, Castleford, and Glenns Ferry stations relating to soil moisture, host plants, and populations of E. tenellus, 1927*

ADELAIDE STATION

Date	Soil moisture			Host plant	Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net			Notes on condition of host plants
	0 to 6 inches	6 to 12 inches	18 to 24 inches			Males	Females	Nymphs	
1927	*Per cent*	*Per cent*	*Per cent*		° *C.*				
May 13	12.14	13.49	17.46	Sophia sophia	1.82	0	0	0	S. sophia 2 inches average, one-half to 4 inches high; S. altissimum rosettes 1 to 3½ inches; S. pestifer 4 to 20 leaves.
				Sisymbrium altissimum	1.64	0	0	0	
				Salsola pestifer		0	0	0	
25	8.35	12.88	15.53	Sophia sophia	1.57	0	0	0	
				Sisymbrium altissimum	1.42	0	0	0	
				Salsola pestifer	1.33	0	0	0	
June 10	7.91	10.32	11.81	Sophia sophia	2.04	0	0	0	S. pestifer short in places and suffering, in other places rank and succulent; only occasional S. altissimum; S. sophia rank and flowering.
				Sisymbrium altissimum	1.38	0	0	0	
				Salsola pestifer	3.05	0	0	0	
22	4.65	6.73	10.93	Sophia sophia	2.95	3	17	0	
				Sisymbrium altissimum	2.15	0	0	0	
				Salsola pestifer	2.84	0	0	0	
July 7	3.25	6.32	8.01	Sophia sophia	2.65	1	0	0	S. pestifer drying; S. altissimum defoliated by larvae; both mustards shed seed.
				Sisymbrium altissimum	1.92	0	0	0	
				Salsola pestifer	1.72	0	1	0	
					4.72				
21	2.45	6.76	4.78	Sophia sophia	2.80	0	0	0	S. sophia all dead except in one small area in a draw; S. altissimum with 50 per cent green stalks; S. pestifer in two lots, one dry, the other rank.
				Sisymbrium altissimum		0	0	0	
				Salsola pestifer	2.33	0	0	0	
					5.4				
Aug. 9	2.58	4.58	6.20	Sophia sophia		13	28	0	S. pestifer along road dense and tall; on west row of quadrats short and withered.
				Sisymbrium altissimum		8	13	1	
				Salsola pestifer	2.81	0	0	0	
					2.90				
26	2.71	4.29	5.45	Salsola pestifer—Roadside	2.60	2	18	0	S. pestifer on roadside dense and succulent; small area of short green growth.
				Salsola pestifer—Succulent	2.46	4	28	2	
				Salsola pestifer—Short, dry	5.1	2	2	0	
Sept. 9	2.90	4.81	5.35	Salsola pestifer—Roadside	2.57	0	2	0	Roadside pestifer still succulent; majority dry and brittle; one small area in transition stage between succulent and dry.
				Salsola pestifer—Succulent	2.37	3	7	4	
				Salsola pestifer—Short, dry	4.70	4	6	0	
21	3.98	3.83	5.58	Salsola pestifer—Roadside		0	0	0	All pestifer dry and brittle.
				Salsola pestifer—Succulent	3.46	12	6	24	
				Salsola pestifer—Short, dry	4.75	8	6	4	

OAKLEY STATION

May 16	10.71	13.39	8.92	Sisymbrium altissimum.	1.25	0	0	0	S. pestifer one-fourth to 4 inches; S. altissimum 6-inch rosettes.
				Salsola pestifer	1.20	0	0	0	
June 1	15.71	18.83	12.90	Sisymbrium altissimum.	1.20	0	0	0	S. altissimum 2 to 6 inches high; S. pestifer 2 to 6 inches, producing thorns.
				Salsola pestifer	1.05	0	0	0	
15	5.16	8.78	9.51	Sisymbrium altissimum.	1.87	0	0	0	S. altissimum in full flower, early seed pods.
				Salsola pestifer	1.06				
July 7	8.11	16.27	9.14	Sisymbrium altissimum.	[1] 1.71 [2] 2.21	0	0	0	S. altissimum still flowering, spiny.
				Salsola pestifer		0	8	0	
14	6.30	9.99	9.57	Sisymbrium altissimum.	[1] 3.01	4	2	0	S. pestifer dying fast; flowers and thorns; S. altissimum practically defoliated and covered with pupal cases.
				Salsola pestifer	3.33	1	0	0	
Aug. 2	4.23	8.70	13.44	Sisymbrium altissimum.	2.30	0	24	12	S. pestifer "dry."
				Salsola pestifer	4.28	0	0	0	
17	5.01	8.08	8.94	Salsola pestifer—					
				Rank	3.76	152	402	60	S. pestifer brittle; S. altissimum dead.
				Dry		80	44	13	
Sept. 2	3.17	7.72	8.39	Salsola pestifer—					
				Rank	3.39	558	332	94	S. pestifer dying through drought while still in flower; patches of green stuff have seeded.
				Dry	4.80	310	65	15	
21	6.27	7.95	4.78	Salsola pestifer—					
				Rank	3.30	172	74	24	Rain has freshened up the pestifer.
				Small		92	30	12	

BURLEY STATION

May 16	10.10	11.17	11.69	Sisymbrium altissimum.	1.36	0	0	0	S. pestifer in tufts 1 to 4 inches high; S. altissimum with 1-inch, 2-inch, and 3-inch rosettes.
				Salsola pestifer	1.29	0	0	0	
June 1	12.36	12.98	12.67	Sisymbrium altissimum.	1.00	0	0	0	S. altissimum to 12 inches high; S. pestifer 2 ½ to 4 inches high.
				Salsola pestifer	1.00	0	0	0	
15	6.69	5.88	13.71	Sisymbrium altissimum.	1.58	0	0	0	S. altissimum in full flower; early seed pods.
				Salsola pestifer	1.33	0	0	0	
July 1	7.14	7.28	8.16	Sisymbrium altissimum.	[1] 1.80 [2] 1.90	3	9	0	S. altissimum still flowering and in fan shape; S. pestifer in full bloom, spiny.
				Salsola pestifer	1.95	0	5	0	
14	4.20	5.66	5.32	Sisymbrium altissimum.	2.45	1	4	0	S. altissimum generally dead but enough left with green upper leaves for sample; enormous numbers of pupal cases on all available leaves. S. pestifer generally prickly and in full flower; small area of more succulent growth.
				Salsola pestifer	3.18	3	8	0	
Aug. 2	2.84	5.01	5.90	Salsola pestifer—					
				Rank	2.22	11	8	4	
				Dry	2.58				
17	5.01	5.64	4.33	Salsola pestifer—					
				Rank	1.82	6	4	3	S. pestifer small and dry looking.
				Dry	3.00	33	24	15	

[1] Stem leaves.

[2] Basal leaves.

TABLE 19.—*Data from the Adelaide, Oakley, Burley, Hansen, Hollister, Castleford, and Glenns Ferry stations relating to soil moisture, host plants, and populations of E. tenellus, 1927*—Continued

BURLEY STATION—Continued

Date	Soil moisture			Host plant	Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net			Notes on condition of host plants
	0 to 6 inches	6 to 12 inches	18 to 24 inches			Males	Females	Nymphs	
1927	*Per cent*	*Per cent*	*Per cent*		° *C.*				
Sept. 2	3.09	4.22	4.45	Salsola pestifer—					
				Rank	2.60	52	8	4	
				Dry	3.94	101	67	39	
21	5.64	5.11	4.33	Salsola pestifer—					
				Rank		89	39	6	
				Dry	3.26				

HANSEN STATION

Apr. 19	13.12	15.81	10.52	Sisymbrium altissimum		0	0	0	S. altissimum plants in tiny rosettes; occasional pestifer.
				Salsola pestifer		0	0	0	
May 11	14.07	14.33	13.16	Sisymbrium altissimum		0	0	0	Rosettes 1¼ to 6 inches in diameter; 3 inches high where bunched.
26	10.62	11.08	11.63	do	1.72	0	0	0	
June 8	5.73	7.66	8.99	do		0	0	0	S. altissimum in full fresh bloom; lower leaves maturing.
23	5.84	7.31	10.27	Sisymbrium altissimum—					
				High ground	2.24	0	3	0	
				Draws	1.43	0	0	0	
July 6	4.22	6.30		Sisymbrium altissimum		0	0	0	S. altissimum all dead; occasional pestifer.
22	4.03	6.07	6.52	Salsola pestifer	1.53	0	0	0	S. pestifer rank and succulent.
Aug. 6	3.47	5.54	7.19	do	1.48	0	0	0	Do.
18	3.53	5.70	7.93	do		0	0	0	Do.
Sept. 6	3.81	5.32	8.79	do	1.15	0	0	0	Do.

HANSEN SUBSTATION A[3]

June 8				Scattered Sophia sophia, little Sisymbrium altissimum.		0	1	0	
23				Sisymbrium altissimum		0	5	0	
July 6				Salsola pestifer		8	2	2	
22				Sisymbrium altissimum		0	0	0	
Aug. 6				Salsola pestifer		68	202	9	
18				do		292	234	140	
Sept. 6				do		209	109	174	

HANSEN SUBSTATION B [4]

June	8				Atriplex rosea, Sisymbrium altissimum, and Sophia sophia, all rank and dense.		1	0	0	
	23				Sisymbrium altissimum rank and dense.		0	1	0	
July	6				Very rank mustard, transitional and rank A. rosea.		0	0	0	
	22				Sisymbrium altissimum		1	0	0	
Aug.	6				do		1	1	0	
	18				do		3	5	5	
Sept.	6				Atriplex rosea		3	1	0	

HOLLISTER STATION

Apr.	28	13.97	21.18		Sophia sophia		0	0	0	Plants just coming up; S. sophia 1 to 2 inches; S. altissimum 1 to 3 inches.
					Sisymbrium altissimum		0	0	0	
May	12	46.34	19.43		Sophia sophia	1.45	0	0	0	S. sophia 1 to 6 inches; S. altissimum 1 to 6 inch rosettes; S. pestifer first true leaves; S. filipes in bloom.
					Sisymbrium altissimum	1.35	0	0	0	
	27	14.35	15.03	14.39	Sophia sophia	1.35	0	0	0	
					Sisymbrium altissimum	1.02	0	0	0	
June	11	10.98	17.04		Sophia sophia	1.71	0	0	0	S. filipes mature; S. altissimum lower leaves drying up but plants in full bloom; S. sophia rank and in full bloom.
					Sisymbrium altissimum	[1] 1.38 / [2] 1.85	0	0	0	
					Sophia filipes	1.91	0	0	0	
	24	5.61	8.51		Sophia sophia	2.66	1	4	0	
					Sisymbrium altissimum	1.99	1	5	0	
					Salsola pestifer		1	2	0	
					Sophia filipes	2.13	0	0	0	
July	12	5.02	7.51		Salsola pestifer	3.0	3	0	0	All mustards have died out and shed seed; occasional pestifer appearing over whole area.
	27	3.81	7.62		do	3.20	10	22	0	S. pestifer flowering and prickly.
Aug.	11	4.12	8.25		Salsola pestifer No. 1	2.46	44	110	10	Two small pure stands of pestifer, both approximately one quadrat in size (fig. 12); few scattered Amaranthus plants found on west side.
					Salsola pestifer No. 2		63	81	9	
					Amaranthus		0	10	15	
	25	3.83	4.49		Salsola pestifer	3.28	34	39	13	
Sept.	7	4.68	6.02		do	3.45	30	14	4	S. pestifer still green.
	26	4.90	5.25		do	3.52	144	70	22	

[1] Stem leaves. [2] Basal leaves. [3] Abandoned farm land intersected by numerous wagon trails. [4] Creek-bottom land flooded in spring.

TABLE 19.—*Data from the Adelaide, Oakley, Burley, Hansen, Hollister, Castleford, and Glenns Ferry stations relating to soil moisture, host plants, and populations of E. tenellus, 1927*—Continued

CASTLEFORD STATION

Date	Soil moisture			Host plant	Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net			Notes on condition of host plants
	0 to 6 inches	6 to 12 inches	18 to 24 inches			Males	Females	Nymphs	
1927	*Per cent*	*Per cent*	*Per cent*		° *C.*				
Apr. 23	15.10	17.56	12.34	Sophia sophia		0	0	0	Plants all very small, one-fourth to one-half inch.
				Sisymbrium altissimum		0	0	0	
May 12	18.05	19.49	13.91	Sophia sophia	1.27	0	0	0	S. filipes 1 to 4 inch blooms; S. altissimum 1 to 8 inch rosettes.
				Sisymbrium altissimum	1.11	0	0	0	
27	14.35	15.03	14.39	Sophia sophia	1.36	0	0	0	Plants too small to sweep.
				Sisymbrium altissimum	1.44	0	0	0	
				Sophia filipes	1.36	0	0	0	
June 11	12.41	10.27	15.38	Sophia sophia	1.45	0	0	0	All mustards rank. S. filipes almost fully seeded; S. sophia and S. altissimum rank and blooming; A. rosea short.
				Sisymbrium altissimum	[1] 1.24 / [2] 1.60	0	0	0	
				Sophia filipes	1.63	0	0	0	
24	6.21	8.26	11.85	Sophia sophia	2.70	2	2	0	
				Sisymbrium altissimum	1.84	0	0	0	
				Sophia filipes	1.07	0	0	0	
July 12	5.89	8.41	11.76	Sophia sophia	2.38	13	34	0	S. filipes shed its seed; A. rosea varies from rank to dry—only small area and that scattered; S. altissimum variable but some flowers remain and average is green; defoliated by larvae and flea beetles; S. sophia has leaves still green even though seed is fully formed.
				Sisymbrium altissimum	2.01	2	30	0	
				Salsola pestifer	2.79	0	0	0	
				Atriplex rosea		12	30	0	
27	4.82	7.56	7.50	Sophia sophia		0	0	0	S. sophia dead; S. altissimum with green stems but defoliated; one small strip 10 by 50 feet (in a "draw," fig. 12) is carrying heavy populations, evidently a concentration; nymphs common on A. rosea; rosea and pestifer over whole area.
				Sisymbrium altissimum	2.10	390	830	294	
				Atriplex rosea	4.46	246	210	186	
Aug. 11	3.97	6.85	2.80	Sisymbrium altissimum	1.84	1,376	456	396	Area referred to above is "green" by virtue of fresh axillary growth.
				Atriplex rosea		635	180	155	
25	4.24	5.33	8.71	Sisymbrium altissimum	2.22	1,180	280	212	Some altissimum still green.
				Atriplex rosea	3.04	390	48	558	
Sept. 7	4.84	6.65	10.54	Sisymbrium altissimum		0	0	0	S. altissimum dead; A. rosea heavily infested with hemipterous species of various kinds.
				Atriplex rosea	3.98	20	30	40	

GLENNS FERRY STATION

Host plant	Substation 1 (dry knoll)				Substation 2 (abandoned farm)			Substation 3 (low-lying alkali ground)				Substation 4 (roadside)			
	Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net			Number of E. tenellus in 100 sweeps of net			Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net			Depression of cell-sap freezing point	Number of E. tenellus in 100 sweeps of net		
		Males	Females	Nymphs	Males	Females	Nymphs		Males	Females	Nymphs		Males	Females	Nymphs
	°C.							°C.				°C.			
Sophia sophia		[1]	[1]	[1]	[2]	[2]	[2]					2.78			
Atriplex rosea									5	11	0	2.55	7	16	0
Do	4.02	45	40	39				2.78	4	6	0		43	62	27
Salsola pestifer	2.35	98	170	32	45	58	29								
B. hirsuta								2.76	0	3	0				
Atriplex rosea	5.10	146	188	96					0	16	0		322	588	146
Salsola pestifer	3.44	374	844	296	147	314	132								
Atriplex rosea—															
Rank	4.70	414	231	114					57	18	12		260	162	186
Dry	5.20	321	108	117											
Salsola pestifer	3.60	540	420	732	374	156	358								

[1] Stem leaves. [2] Basal leaves. [3] Total number of *E. tenellus*, 33. [4] Total number of *E. tenellus*, 34.

119346—30——4

TABLE 20.—*Physical data obtained from soil samples from six desert observation stations in the Twin Falls district, Idaho, 1927* [1]

Station	Depth	Moisture equivalent	Wilting coefficient [2]	Soluble salts [3]	Station	Depth	Moisture equivalent	Wilting coefficient [2]	Soluble salts [3]
	Inches	*Per cent*	*Per cent*	*Parts per million*		*Inches*	*Per cent*	*Per cent*	*Parts per million*
Adelaide	0–6	17.5	9.5	2,820	Hansen	0–6	21.6	11.7	1,540
	6–12	21.3	11.5	2,340		6–12	21.8	11.8	1,420
	18–24	26.6	14.5	2,060		18–24	24.0	13.0	1,840
Oakley	0–6	20.6	11.2	640	Hollister	0–6	22.3	12.1	4,180
	6–12	23.4	12.7	640		6–12	24.7	13.4	3,620
	18–24	26.4	14.3	1,220		0–6	22.3	12.1	1,460
Burley	0–6	19.8	11.8	3,120	Castleford	6–12	22.9	12.4	1,440
	6–12	20.6	11.2	2,440		18–24	23.0	12.5	1,580
	18–24	24.6	13.4	2,060					

[1] Determined in the Bureau of Chemistry and Soils.
[2] Based on the Briggs-Shantz formula (*5*).
[3] Based on air-dry soil.

The data in Table 19, showing the seasonal growth of the host plants, the depression of the freezing point of the cell sap, the percentage of soil moisture present, and the associated populations of *E. tenellus*, are practically self-explanatory. In general it can be said that the life history of the short-lived annuals was normal, maturity coming before unfavorable cell-sap concentrations had been reached; that the season's development furnished a succession of host plants, thus providing ideal conditions for the breeding of huge populations of the insect, following the conditions prevailing during the preceding winter and during the summer of 1926 (see sections on hibernation and forecasting of outbreaks, pp. 58 and 66); and that *S. pestifer*, being favorable for the whole season, is most important from the standpoint of overwintering populations.

Data from the Oakley station suggest that *S. pestifer* receives large populations from the maturing mustards growing in close proximity.

The Hansen station, on which *S. altissimum* predominates, illustrates the fact that the succession of host plants is necessary before large overwintering populations can be developed. In 1926 this area was completely dried out very early in the season, and the scattered *S. pestifer* growing in that area did not germinate until after the late summer rains. It was practically impossible for *E. tenellus* populations to exist therefore at that place, and they will probably not develop until after another favorable year.

The Hansen substations A and B are added to the record for purposes of comparison. In the case of substation A the succession of *S. pestifer* was provided, with the result that a very large population was developed before the end of the season; in the case of substation B, where all the host plants except *S. pestifer* were present, the growth was so dense and the situation so humid for most of the season, owing to the low-lying swampy ground, that populations were kept down, even on the *Atriplex rosea*, which usually is a rather favorable host in the middle of the season.

The great increase in population which occurred at the Castleford station between the 12th and 27th of July was due to the fact that the *S. altissimum* had been almost completely defoliated over practically the whole area by the larvae of *Plutella maculipennis* Curt.

A small strip of the area was covered with *altissimum* which sent out fresh axillary growth after defoliation. It was from this narrow strip that the population recorded was collected.

The Glenns Ferry station could not be treated in a manner similar to the others because of the character of the country, so data were obtained from four substations representing typical *tenellus* breeding grounds.

THE HOST PLANTS OF EUTETTIX TENELLUS AND ITS MIGRATIONS

The experience of the last four seasons justifies the conclusion that the movements of *E. tenellus* into beet fields in the area studied are largely governed by its host-plant relationships. Two conditions are met with, although no sharp line of demarcation between the two can be made. If conditions are favorable the previous fall and large populations successfully hibernate, an extremely dry spring, such as occurred in 1926, proves disastrous to beet growers. Under such conditions the mustards attain a short rapid growth (pl. 6, A) but are killed as a consequence of drought, while *Salsola pestifer* and *Atriplex rosea* either do not germinate at all or are killed off before reaching a height of more than a few inches. On such occasions there is a general movement of *E. tenellus* from environments which are no longer suitable. It is during seasons of this type that the most severe damage is done to beet fields. If the drying up of the desert is uneven, the movement of the insect is likely to be of a dribbling type, such as occurred in 1928.

The movements into beet fields which occur to some extent apparently every year in the area studied are more difficult to explain, but from the experiences of 1925 and 1927 the same explanation, i. e., an unfavorable host-plant condition, probably holds true. The succession of host plants throughout the season is such as to force the conclusion that *tenellus* populations on *S. pestifer* arise from *tenellus* individuals which moved there during the early spring from some other host plant. If *S. pestifer* is so favorable a host plant, why are there migrations into beet fields in years when that plant is present in a succulent condition at the time of the migration?

In the fall of the year there is a concentration of the insect on those plants, even in *pestifer* stands, which are most favorable late in the season. In the spring the insect moves off to the mustard, and in the course of the early season becomes well distributed throughout the mustard areas. These are very considerable in extent, often in pure stands, with *S. pestifer* more or less limited to the roadsides. The late spring movement of the insect to *S. pestifer* is probably a matter of the contiguity of the *pestifer* to the mustards from which the insect moves. That *E. tenellus* will move from plant to plant within a small area has been demonstrated before (*6*). Even more striking evidence is contained in the data from the Castleford station (Table 19), where the movement of *E. tenellus* to a small patch of *S. altissimum*, which continued green after the surrounding plants had been defoliated and had died, is clear from the population data. The fact that populations of the insect on *S. pestifer* increase gradually throughout the season, without any apparent sudden diminution, supports the hypothesis that the insect does not normally migrate from *S. pestifer*. The movement from the mustards has probably two directions, one to *S. pestifer* which happens to be growing close

to the edge of a mustard stand, and the other to the cultivated areas. In this way the maintenance of the insect on the desert is provided for as long as the host plant succession is complete.

In 1927 there was a movement of leaf hoppers on June 13. At this time *S. altissimum* and *S. sophia* were green and succulent apparently from Pocatello, Idaho, to Portland, Oreg. *S. filipes* (Table 19) was fully mature and seeded at that time and there were considerable areas of this species present. Other factors than those already suggested may and probably did operate during the season of 1927. In the data from the Castleford station the factor of competition suggests itself strongly. Larvae of *Plutella maculipennis* had stripped the leaves and even the flowers of *S. altissimum*, and this condition was evident over the entire breeding ground. (Pl. 6, B.)

Another factor for consideration is that of a migratory instinct when the spring brood has made its appearance. It is difficult to separate this from consideration of host-plant conditions, since the spring host plants are well on the way to maturity when the spring brood appears. The competition of other species has been mentioned, but the movement into the beet fields in 1927 was certainly not due to overcrowding of *E. tenellus*, because just prior to the migration the usual methods of quantitative collecting showed very few *E. tenellus* in 50 or 100 sweeps of the net. The instinct on the part of the insect to migrate when the spring brood has developed may be a response to a stimulus brought about by maturing plant tissue. The insect certainly continues in the desert on the mustards as long as there are any plants left which are still green and succulent.

EUTETTIX TENELLUS AND THE INSECT COMMUNITY

The insect community at any given time represents a summarized effect of a large number of factors, physical and biotic, external and internal, interrelated and independent. This leads to the concept of the community as an entity. As in any other community, certain species dominate or predominate according as they are fitted by structure, adaptability, or reproductive power to use the environment more efficiently or economically than others. In an environment which normally limits a species to an inferior position in the community, abnormal conditions for a short time during a critical period may elevate such a species temporarily to predominance. Such was the case during 1927 with *Plutella maculipennis* in southern Idaho.

Observations in the same localities over a series of years will provide data on when these periods of predominance occur as well as on the possible factors responsible. Since insect outbreaks are often instances of just such occurrences, the desirability of observations on insect communities is obvious. If a species is consistently predominant, such predominance can be taken as evidence that the environment is of an optimum nature for that particular species. The converse does not necessarily hold true, since the biotic potential of insects differs so much that a species may be at optimum and yet not be predominant.

In Table 21 are data on the principal species represented in the quantitative collections. As previously mentioned, data from a series of years are necessary before interspecific relationships can be

PLANTS OF SISYMBRIUM ALTISSIMUM

A, Plants of *S. altissimum* abnormally mature and stunted because of drought; B, solitary plant of *S. altissimum* with lower leaves remaining but with small leaves gone and stems covered with pupal cases of *Plutella maculipennis*.

worked out, but the data for this one season point to the following general conclusions:

(1) Only a few species are represented by more than one or two specimens per collection of 100 sweeps.

(2) The entire area covered by the desert observation stations is fairly homogeneous with respect to insect fauna.

(3) The mustards, with their rapid growth in the spring, furnish opportunity for predominance of leaf-eating forms of wide geographic distribution. This predominance is lost later in the season to other species which are able to take advantage of the host-plant succession.

(4) *E. tenellus*, having capacity to use environments beyond the limits of tolerance of some other species, as far as the physical factors are concerned, succeeds to a predominance often amounting to numbers greater than all other species combined.

(5) The factor of competition between species is obviously greater early in the season and on the mustards. This competition is important from the standpoint of the environment, being favorable for *tenellus* at the critical time in the development of the sugar beet.

(6) After *E. tenellus* is established on *Salsola pestifer* there is little competition on the part of other species, and it is evident that movement from Salsola is unlikely under normal conditions.

The insects mentioned in Table 21 include one species of Lepidoptera, *Plutella maculipennis* Curt.; nine species of Hemiptera, *Eutettix tenellus* Baker, *Nysius ericae* (Schill.), *Lygus elisus* Van D., *Agallia sanguinolenta* (Prov.), *Plagiognathus longipennis* Uhl.,[7] *Atmoscelis modestus* (Van D.), *Geocoris bullatus* (Say), *Euscelis exitiosus* (Uhl.), and a species of Thamnotettix; also *Phyllotreta albionica* Lec., a chironomid, a braconid, a dipteron, a coleopteron, spiders, ants, bee flies, macrolepidopterous larvae, nymphs of a hemipteron, grasshopper nymphs, and some incidental species.

[7] This species is so similar in general facies to *Orthotylus coagulatus* Uhl. that the numbers given in the table include both species.

TABLE 21.—*Principal species of insects collected from host plants of Eutettix tenellus, Twin Falls district, Idaho, 1927*

CASTLEFORD STATION

Date of collection	Sophia sophia		Sisymbrium altissimum		Salsola pestifer		Atriplex rosea	
	Insect	Number	Insect	Number	Insect	Number	Insect	Number
June 11	Plutella maculipennis [1]	71						
	Dipteron	69						
	Phyllotreta albionica	6						
24	P. maculipennis	322	(2)					
	Nysius ericae	84						
	P. albionica	42						
	Chironomid	23						
	Lygus elisus	8						
	Eutettix tenellus	4						
July 12	P. albionica	958	P. albionica	3,686			P. albionica	50
	P. maculipennis	87	P. maculipennis	250			P. maculipennis	25
	Braconid	32	A. sanguinolenta	12			A. sanguinolenta	15
	Agallia sanguinolenta	23	E. tenellus	16			Atmoscelis modestus	8
	L. elisus	19					E. tenellus	42
	Plagiognathus longipennis	15						
	E. tenellus	47						
27			P. albionica	4,600			P. albionica	72
			L. elisus	158			A. sanguinolenta	66
			A. sanguinolenta	72			Spiders	60
			P. maculipennis	116			Geocoris bullatus	24
			Spiders	62			N. ericae	12
			E. tenellus	1,498			E. tenellus	642
Aug. 11			P. albionica	286			N. ericae	125
			L. elisus	214			A. sanguinolenta	45
			Dipteron	92			E. tenellus	1,000
			A. sanguinolenta	28				
			E. tenellus	2,228				
25			L. elisus	172			N. ericae	516
			P. albionica	116			L. elisus	76
			Spiders	60			A. sanguinolenta	54
			Ants	32			A. modestus	48
			E. tenellus	1,672			E. tenellus	996

HOLLISTER STATION

June 24	P. maculipennis	206	P. maculipennis	2,771				
	N. ericae	115	Ants	124				
	P. albionica	31	P. albionica	24				
	Chironomid	14	L. elisus	9				
	L. elisus	5	E. tenellus	8				
	E. tenellus	5						

July 12				P. maculipennis	250		
				P. albionica	70		
				L. elisus	35		
				E. tenellus	1		
Aug. 11				N. ericae	316		
				L. elisus	68		
				A. sanguinolenta	26		
				Small coleopteron	16		
				E. tenellus	164		
25				L. elisus	37		
				N. ericae	15		
				Ants	14		
				A. sanguinolenta	9		
				E. tenellus	86		
Sept. 17				L. elisus	64		
				N. ericae	16		
				A. sanguinolenta	12		
				Ants	18		
				E. tenellus	48		
26				L. elisus	54		
				A. sanguinolenta	22		
				Spiders	22		
				F. albionica	8		
				E. tenellus	246		

GLENNS FERRY STATION

July 8				Euscelis exitiosus	32	A. modestus	400
				G. bullatus	24	A. sanguinolenta	34
				A. modestus	12	G. bullatus	55
				P. albionica	6	Spiders	15
				Spiders	8	Macrolepidopterous larvæ	31
Aug. 5				E. tenellus	300	E. tenellus	132
				G. bullatus	108	A. modestus	3,000
				Spiders	26	G. bullatus	98
				A. modestus	18	Spiders	24
				A. sanguinolenta	10	L. elisus	6
				L. elisus	4	E. tenellus	430
				E. tenellus	1,514		
Sept. 5				G. bullatus	102	A. modestus	240
				L. elisus	12	G. bullatus	21
				Spiders	21	L. elisus	15
				E. tenellus	1,692	A. sanguinolenta	15
						E. tenellus	759

[1] On the same date 253 *Plutella maculipennis* were collected from *Sophia filipes*.

[2] Collection lost.

TABLE 21.—*Principal species of insects collected from host plants of Eutettix tenellus, Twin Falls district, Idaho, 1927*—Continued

ADELAIDE STATION

Date of collection	Sophia sophia		Sisymbrium altissimum		Salsola pestifer		Atriplex rosea	
	Insect	Number	Insect	Number	Insect	Number	Insect	Number
June 10	P. longipennis	160			P. maculipennis	6		
	N. ericae	156			Coleopteron	1		
	Dipteron	84			Grasshopper nymphs	2		
					E. tenellus	0		
22	P. albionica	693	P. maculipennis	291	P. maculipennis	379		
	P. maculipennis	123	P. albionica	129	P. albionica	73		
	Thamnotettix sp	30	L. elisus	12	Grasshopper numphs	3		
	E. tenellus	20	P. longipennis	4	E. tenellus	0		
			E. tenellus	0				
July 7	P. albionica	2,253	P. albionica	2,521	Macrolepidopterous larvæ	141		
	P. longipennis	50	P. maculipennis	884	Coleopteron	6		
	P. maculipennis	63	Coleopteron	31	Flea beetles	9		
	N. ericae	24	P. longipennis	20	N. ericae	2		
	Coleopteron	24	L. elisus	8	E. tenellus	1		
	L. elisus	13	E. tenellus	0				
	E. tenellus	1						
21	Hemipteron nymphs	4,758	P. albionica	2,038	Macrolepidopterous larvæ	37		
	P. albionica	201	P. maculipennis	25	P. albionica	8		
	N. ericae	35	E. tenellus	0	G. bullatus	2		
	E. tenellus	0			E. tenellus	0		
					Roadside			
Aug. 9					Incidental species	15		
					E. tenellus	41		
					Short-dry			
					Incidental species	7		
					E. tenellus	0		
					Normal			
					G. bullatus	4		
					Spiders	2		
					P. albionica	1		
					E. tenellus	32		

					Roadside			
					N. ericae	52		
					L. elisus	8		
					Ants	4		
					E. tenellus	10		
					Short-dry			
26					Incidental species	24		
					E. tenellus	3		
					Normal			
					Bee flies	50		
					N. ericae	14		
					L. elisus	12		
					E. tenellus	34		

THE WINTER ENVIRONMENT AND HIBERNATION OF EUTETTIX TENELLUS

EXPERIMENTS OF 1925–26 AND 1926–27

Field studies in hibernation during the winter of 1925–26 failed through faulty technic. The insects were placed in 1-pint cartons, which were ventilated at both ends through openings covered with small pieces of wire gauze. The experiments were planned on the assumption that under Idaho conditions the insect would undergo true hibernation. Observations demonstrated that such is not the case. *E. tenellus* in southern Idaho does not hibernate; it simply responds to temperatures below its developmental zero by becoming inactive. At some time during every month of the winter of 1925–26 *E. tenellus* were captured which were sluggish but nevertheless active. The indications are that the overwintering insect is so constituted that it can take advantage of periods of active temperature, even though they are of short duration, during the entire winter. (Fig. 1, A.) Hibernation cages for these studies must contain suitable food or the insects will perish from starvation during the winter.

The cases used for studies during the winter of 1926–27 were built to meet this need for food. The large cages each had a wooden base containing soil about 10 inches deep in which host plants were planted. (Pl. 7, A.) The covers were of cloth or of a commercial glass substitute. Covers of celluloid, such as is used for automobile curtains, were used over host plants set in 10-inch pots. (Pl. 7, B.)

In one series of large cages covered with cloth or a commercial glass substitute, 250 females were placed in each, together with a varying number of males. The collections were made during the first 11 days of September. The results are given in Table 22. In another series of similar cages the number of *tenellus* used was not uniform, but ranged from 36 to 250 females per cage. These were collected during October and November. The data are presented in Table 23.

In the smaller cages covering the pots, 50 females were placed in each cage. The collection period was from September 1 to October 21. The data are shown in Table 24.

TABLE 22.—*Data on hibernation of Eutettix tenellus collected during the early part of September, 1926; 250 females to each cage; Twin Falls, Idaho*

Date collected	Type of cage	Food supply	Date cage brought in	Number insects recovered	Remarks
1926			1927		
Sept. 9	Cloth	Beets and grass	Mar. 17	39	Some distinctly light-colored forms. Developing ovaries in 50 per cent.
7	Glass substitute.	do	do	50	Also 1 last-instar nymph which emerged as adult in 2 days at 85° F.
4	Cloth	S. pestifer	Mar. 18	0	No food; thistle dead and no other plants in cage.
8	Glass substitute.	do	do	0	No food. Spider web in cage.
4	do	Knotgrass and rank grass.	do	5	
11	Cloth	Knotgrass and grass.	do	16	

TABLE 23.—*Data on hibernation of Eutettix tenellus collected during October and November, 1926; Twin Falls, Idaho*

Date collected	Type of cage	Food supply	Date cage brought in	Number insects recovered	Remarks
1926			1927		
Oct. 25 to Nov. 11.	Glass substitute.	Knotgrass and grass.	Mar. 26	7	150 females put in. Spider a factor.
Oct. 25 to Nov. 17.	Cloth	do	do	0	132 females put in. Agallia recovered, but no record of number caged.
Nov. 8-17	do	S. pestifer and grass.	Mar. 28	4	6 Agallia recovered. 162 female tenellus put in.
Nov. 23	Glass substitute.	do	do	0	37 females put in.
Oct. 9	do	Beets and grass.	Mar. 31	17	Developing ovaries in 50 per cent. 250 females put in cage.
Do	Cloth	do	do	3	36 females put in.

TABLE 24.—*Data on hibernation of Eutettix tenellus in celluloid cages placed over host plants in pots, 1926 and 1927; 50 females to each cage; Twin Falls, Idaho*

Date collected	Food supply	Date cage brought in	Number insects recovered	Remarks
1926				
Sept. 1	Beets and grass	Dec. 23, 1926	23	2 nymphs.
2	do	Dec. 30, 1926	19	
3	do	Dec. 23, 1926	11	
14	do	Dec. 30, 1926	16	
14	do	Jan. 3, 1927	18	
17	do	Dec. 31, 1926	22	
17	do	Dec. 30, 1926	(?)	
25	do	Feb. 21, 1927	1	
22	A. rosea	Feb. 5, 1927	0	No food.
24	Knotgrass and grass	do	13	Developing ovaries in 8.
24	Knotgrass	do	0	No food.
25	S. pestifer	Feb. 28, 1927	0	Do.
Oct. 2	do	Feb. 21, 1927	0	Do.
4	do	Feb. 28, 1927	0	Do.
4	do	do	0	Do.
6	Beets	Dec. 21, 1926	0	
6	do	do	0	
6	do	Jan. 3, 1927	1	
6	Beets and grass	Dec. 27, 1926	0	
6	do	Jan. 6, 1927	14	
21	Rank knotgrass	do	12	
Sept. 3	Beets and grass	Feb. 17, 1927	2	
25	Knotgrass and grass	do	14	Developing ovaries. A half-grown parasite.
Oct. 16	do	do	5	
15	Rank knotgrass	Feb. 23, 1927	8	11 Agallia also. 2 tenellus with developing ovaries.
4	S. pestifer	Feb. 25, 1927	0	No food.
21	Rank knotgrass	Feb. 23, 1927	6	
5	Knotgrass and grass	Feb. 25, 1927	2	Spider in cage.

An analysis of the data of Tables 22 and 23 indicates that *E. tenellus* collected early in September survived the winter better than those collected in October, the percentage of survival being 11 per cent in the case of September collections and 4 per cent for the October collections.

The insects were all from the same source, the only difference being that the later collections were of insects which had perforce left the beet field and were feeding on the plants growing along the fence rows. Feeding on some of these may have reduced the capacity of the insect to survive the winter.

The importance of food during the winter is emphasized by the data. In no case where the fall host plant alone (*S. pestifer* or *A.*

rosea) was available in the cages did the insect survive. The beet plants remained suitable for food during the entire winter.

Data in Table 24 (celluloid cages, 50 females to each cage) indicate that the number recovered was very high for early collections brought in during the latter part of December. Before the end of this period temperatures below 0° F. had been encountered. This was followed by a period of milder weather until January 21, when there was another period of three days of temperatures below zero. Collections brought into the laboratory after this second period of cold weather had a lower rate of recovery, although the number of cases available is not sufficient for conclusive evidence. The general indication is that the later the collection and the longer the exposure to temperatures below zero, the greater the rate of mortality. Figure 1, B, shows that temperatures in the celluloid-covered hibernation cages fluctuated considerably as compared with those at the soil surface.

One of the celluloid-covered cages which was brought in December 30, 1926, showed a recovery of 23 females and 2 nymphs. The insects were returned to the cage and on the evening of the same day the cage was placed outdoors for a second time. The minimum standard-shade temperature that night was 10° F. The next morning the cage was brought into the laboratory again, and 18 females recovered. A duplicate of this experiment showed an initial recovery of 11 females but none recovered after the second exposure.

Three cages brought in from the field January 6, 1927, were used for a similar experiment. The insects were returned to the cages and taken outdoors on January 7. The minimum temperature from that date to January 19 was 23° F. Snow commenced to fall on that date, so one cage was brought into the laboratory as a check and the tops were removed from the other two cages to expose the insects to the snow. Rain followed that same day and more snow the following day. Minimum temperatures of below zero prevailed for the following three days. The tops of the cages were replaced and the cages returned to the laboratory January 25. None of the insects recovered. In the check cage all the insects recovered.

The data in the two preceding paragraphs are the results of experiments on the effect of alternate freezing and thawing and exposure to contact moisture. The results indicate that exposure to contact moisture prior to the incidence of low temperatures was a factor in lessening the resistance of the insect to low temperatures.

EXPERIMENTS OF 1927-28

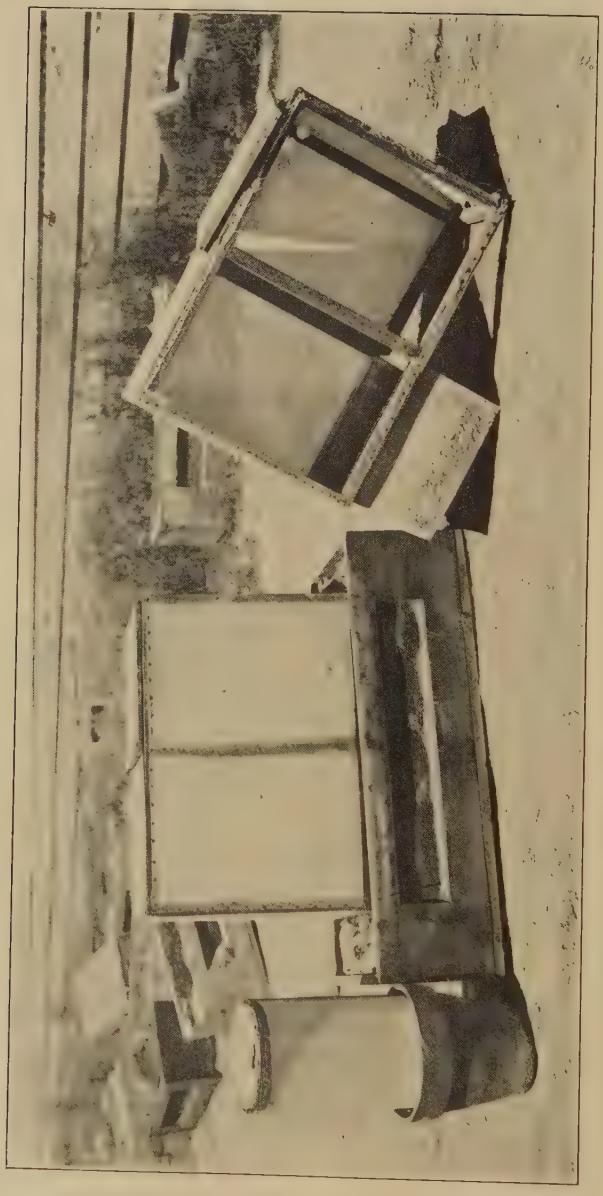
HIBERNATION STUDIES

In the hibernation studies of the winters of 1927–28 the type of cage covering was standardized, unbleached muslin being used exclusively. (Pl. 8.) This was decided upon because the experience of the previous season had shown that the other materials used did not materially affect the temperatures on the soil surface, whereas the celluloid cages used on the large plant pots, though providing more fluctuating temperatures, were of such construction as to make accurate measurement of temperatures very doubtful.

The suggestions furnished by experiments of the 1926–27 season, indicating that time of collection and exposure to winter moisture conditions were of significance, were followed. The small cages were

HIBERNATION CAGES USED IN THE WINTER OF 1926-27 AT TWIN FALLS, IDAHO

A, Large cages with covers of a glass substitute; B, small celluloid cages over plants in 10-inch pots.



HIBERNATION CAGES USED IN THE WINTER OF 1927-28 AT TWIN FALLS, IDAHO

brought in in two lots a month apart; the large cages were so constructed that one half could be exposed to rainfall and snow, and the other half left covered. In each large cage 150 female *tenellus* were placed in each side. A varying number of males were put into each cage. When the *Salsola pestifer* was transplanted into the cages, seed of *S. altissimum* and *S. sophia* was scattered on the soil to germinate during the late fall and provide food when the *S. pestifer* was completely dried up.

The results of two experiments on the effect of wet soil surface are recorded. (Table 25.) In these cases one side of the cage was fitted with a tight metal base (pl. 8) which was filled with soil, the host plants were transplanted, and the soil was then kept wet. This side of the cage was also fitted with the removable top used in the other large cages.

TABLE 25.—*Hibernation studies in large cloth cages, 150 Eutettix tenellus on exposed side and 150 on closed side; brought in from field March 1 to 4, 1928, Twin Falls, Idaho*

Date insects were collected	Hosts from which insects were collected	Hosts in cage	Number recovered in exposed side	Number recovered in closed side	Remarks
1927					
Sept. 1	Beets	Beets and mustards	34	36	
	do	do	25	52	
	S. pestifer	S. pestifer and mustards.	31	29	
	do	do	44	76	One nymph recovered from exposed side.
15	do	do	7	60	Food supply on exposed side doubtful.
	do	do	60	82	
	Beets	Beets	58	53	
	do	do	35	46	
27	S. pestifer	S. pestifer and mustards.	2	19	
	do	do	81	55	
	Beets	Beets	29	48	
Oct. 10	do	do	16	8	Holes in cage.
	do	do	5	14	
	do	Polygonum and grass, typical fence-row complex.	3	0	
22	S. pestifer	S. pestifer and mustards.	0	0	No food, because mustards did not germinate.
	Rabbit brush	Rabbit brush	0	2	
Nov. 2	Freshly germinated S. altissimum.	Freshly germinated S. altissimum.	0	8	
Sept. 27[1]	S. pestifer	S. pestifer and mustards.	1	25	Cloth rotted on the exposed side; escape was possible.
	Beets		0	53	Exposed side had thin coat of ice over soil surface. Plant was in fair condition.

[1] These 2 cages were fitted with a metal base on the exposed side and the soil was saturated with water.

On December 10, 1927, a snowstorm started, so the removable tops were taken from all the large hibernation cages. Because of the height and position of the cages, all did not receive an equal fall of snow, but enough to provide some free water in the cage with the first thaw. The tops were left off until December 29.

Table 25 presents the data obtained from the large cages. The recovery in the exposed sides of these cages compared with that from those not exposed strongly supports the hypothesis that wetting or

exposure to contact moisture reduced the capacity to hibernate. This was even more pronounced in the case of the cage where the exposed half was underlaid with saturated soil.

The data from the small cages are presented in Tables 26 and 27. The indications that appeared in the 1926–27 results that the time of collection had some effect on hibernation are not supported by the results of these experiments. This effect may, however, be associated with the environmental complex as it occurred in that season, even though the factors responsible are not understood.

TABLE 26.—*Hibernation studies in small cloth cages, 50 Eutettix tenellus to each cage; brought in from field January 2 and 3, 1928; Twin Falls, Idaho*

Date insects were collected	Hosts from which insects were collected	Hosts in cage	Number recovered	Remarks
1927				
Sept. 3	Salsola pestifer	Salsola pestifer and mustards	4	Food supply doubtful.
	Beets	Beets	0	No food.
	do	do	19	
8	S. pestifer	S. pestifer and mustards	35	
	Beets	Beets	24	
	do	Polygonum	22	
16	do	do	22	Spider web.
	do	Beets	36	
21	S. pestifer	S. pestifer and mustards	26	
	Beets	Polygonum	12	
	do	Beets	25	
27	S. pestifer	S. pestifer and mustards	11	
	Beets	Beets	11	
	do	Polygonum	13	
Oct. 6	S. pestifer	S. pestifer and mustards	3	
15	Beets	Beets	22	
17	do	Polygonum	9	
18	S. pestifer	S. pestifer and mustards	0	Food doubtful.
Nov. 4	Beets	Beets	18	
	do	Polygonum	22	

TABLE 27.—*Hibernation studies in small cloth cages, 50 Eutettix tenellus in each cage; brought in from field February 1 to 3, 1928; Twin Falls, Idaho*

Date insects were collected	Hosts from which insects were collected	Hosts in cage	Number recovered	Remarks
1927				
Sept. 3	Beets	Polygonum	1	Food dried up; small plant of grass in cage.
	do	Beets	12	
8	Salsola pestifer	Salsola pestifer and mustards	10	
	Beets	Beets	21	
	do	Polygonum	19	
16	do	Beets	19	
	S. pestifer	S. pestifer and mustards	1	Food gone; Sophia sophia had germinated and died.
21	Beets	Polygonum	1	No food.
	do	Beets	33	
	S. pestifer	S. pestifer and mustards	1	No food.
27	Beets	Beets	6	
	do	Polygonum	10	Only dry Polygonum in cage.
	S. pestifer	S. pestifer and mustards	13	Grass only in cage.
Oct. 7	Beets	Polygonum	11	Grass and Sisymbrium altissimum in cage.
	do	do	8	
	do	Beets	17	
	do	do	7	
15	do	do	19	
	do	Polygonum	3	Only dry Polygonum in cage.
20	S. pestifer	S. pestifer and mustards	0	No food.
Nov. 4	Beets	Beets	10	
	do	Polygonum	0	No food.

The results in Tables 26 and 27 indicate that some reduction in numbers took place in the field cages from January 2 to February 1. By a comparison of the experiments of the two winters 1926–27 and 1927–28, it is seen that the percentage of survival was much greater in 1927–28 than it was the preceding winter, even though the difference can not be explained on a basis of differences in soil-surface temperatures.

LABORATORY EXPERIMENTS ON THE EFFECT OF LOW TEMPERATURES

A commercial ice house was used for most of the experiments with low temperatures. In the earliest experiment (Table 28) the insects were caged over small beets, but this method was abandoned and thick-walled tubes, lined with blotting paper, were used as cages.

In one experiment four tubes, each containing 30 *E. tenellus* collected from beets and *S. pestifer* on September 18, 1927, were placed in a commercial ice house in which the temperature varied. At the end of 2, 4, 6, 8, 10, and 12 hours, respectively, the temperatures were −5°, −3°, −1°, −6°, 0, and −5° F. Two tubes were examined at the end of 8 hours, and two at the end of 12 hours. All the insects were dead.

In another experiment four tubes, each containing 30 *E. tenellus* collected from beets and *S. pestifer* on September 16, 1927, were placed in a commercial ice house with a constant temperature of −12° F. The insects in two tubes showed feeble movements when examined at the end of four hours, but all died. The insects in the two other tubes were all dead when examined at the end of six hours.

The data from other similar experiments are presented in Tables 28 to 32.

TABLE 28.—*Data on Eutettix tenellus in cages exposed to varying temperatures' July 27, 1926*

(Twenty insects were caged over each of 10 beet plants in a commercial ice house at a temperature which varied. Temperature at end of each period is listed in the table. Plants exposed for one hour were not injured; all the others were frozen. Position of insects on being brought into higher temperature showed that they had sought cracks in the soil.)

Time of exposure (hours)	Temperature at end of period	Series 1		Series 2	
		Recovered	Dead	Recovered	Dead
	°F				
1	16	20	0	20	0
2	15	2	18	2	18
4	−2	4	16	3	17
6	−2	1	19	1	19
8	−2	3	17	2	18

TABLE 29.—*Data on Eutettix tenellus, 25 per tube, in 10 wide glass cylinders lined with blotting paper, exposed in a commercial ice house with varying temperature, July 29, 1926*

Time of exposure (hours)	Temperature at end of period	Series 1		Series 2	
		Recovered	Dead	Recovered	Dead
	°F				
1	−5	14	11	[1] 15	8
2	−15	0	25	3	22
4	−15	0	25	0	25
6	−15	0	25	0	25
8	−6	0	25	0	25

[1] 2 can not be accounted for; probably escaped.

TABLE 30.—*Data on Eutettix tenellus in 10 glass cylinders lined with blotting paper, each containing 25, placed in a commercial ice house at −14° F.; insects taken from beet fields August 3, 1927*

Time exposed to cold (hours)	Series 1				Series 2			
	Recovered		Dead		Recovered		Dead	
	Male	Female	Male	Female	Male	Female	Male	Female
1	10	0	12	3	9	7	1	8
2	5	2	14	3	[1] 2	0	8	9
5	[2]	[2]	[2]	[2]	[2]	[2]	[2]	[2]
6	[2]	[2]	[2]	[2]	[2]	[2]	[2]	[2]
8	[2]	[2]	[2]	[2]	[2]	[2]	[2]	[2]

[1] 6 insects not accounted for. [2] All dead.

TABLE 31.—*Data on Euttetix tenellus collected September 1, 1927, placed in six tubes, 30 to each tube, and exposed in an ice house at a temperature of −10° F.*

Time exposed to cold (hours)	Insects from beet field				Insects from Salsola pestifer			
	Recovered		Dead		Recovered		Dead	
	Male	Female	Male	Female	Male	Female	Male	Female
1	16	7	7	0	[1] 7	7	8	5
2	[2]	[2]	[2]	[2]	[2]	[2]	[2]	[2]
4	[2]	[2]	[2]	[2]	0	1	16	13

[1] 3 insects not accounted for. [2] All dead.

TABLE 32.—*Data on Eutettix tenellus collected September 15, 1927, following rain and frost, and exposed in 4 tubes, 30 to a tube, in an ice house at 6° to 8° F.*

Time exposed to cold (hours)	Insects from beet field		Insects from Salsola pestifer	
	Recovered	Dead	Recovered	Dead
2	28	2	28	2
4	23	7	16	14

Table 33 lists data obtained by confining the insects in a silk bolting-cloth bag which, with a thermocouple inserted, was pushed to the bottom of a thick-walled glass tube. The tube was then hung within a copper expansion coil and the temperature reduced by passing carbon dioxide through the coil.

TABLE 33.—*Data on Eutettix tenellus brought into the laboratory, placed in freezing tubes, and subjected to low temperatures obtained by use of carbon dioxide, 1926 and 1927*

Date	Lowest temperature	Time factor	Remarks
1926	° F.		
Sept. 8	5	Immediately withdrawn from tube.	26 adults and 4 nymphs from field. Only 2 adults killed, which were males; 2 nymphs dead.
14	7	Held at 7° for 7 minutes; warmed up in 15 minutes more.	9 adults, 2 dead. 7 nymphs, 3 dead. Recovered specimens not normal. 1 adult fluttered its wings at a great rate. Nymphs all groggy.
Nov. 17	−36.5	5 minutes going down. Taken out at once.	All dead.
17	−7	Down in 15 minutes; warmed up slowly.	3 out of 12 survived. All males.
17	−7	Removed instantly from tube....	1 partly recovered. All were dead in 30 minutes. Males.
[1] 22	−2	Down in 45 minutes; warmed up slowly for 35 minutes.	11 males, 7 females. None recovered.
23	5.4	Down in 15 minutes; warmed up in 10 minutes.	From same lot as preceding experiment. 11 males, 7 females. 5 females recovered.
25	−2	Down in 5 minutes from 32°; warmed up slowly.	10 males. All dead.
1927			
Aug. 6	−7	Down in 4 minutes; 60 minutes to warm up.	No recovery of tenellus. 1 Agallia nymph survived.
6	0	Down in 8 minutes; 25 minutes to warm up.	No recovery.
Sept. 9	7	Down in 6 minutes; 60 minutes to warm up.	All recovered, including nymphs, except 1 male and 1 female.
15	7	Down in 15 minutes; 30 minutes to warm up.	All recovered except 3 males.
15	1	Down in 10 minutes; 45 minutes to warm up.	All recovered except 4 males.
15	−2	Down in 20 minutes; 25 minutes to warm up.	None recovered.

[1] Wet weather began soon after Nov. 17, 1926.

DISCUSSION OF THE HIBERNATION STUDIES

The temperature data of Tables 2 and 3 and Figures 5, 6, and 7 are of great interest in connection with the data on the overwintering of the insect. From these tables it is seen that at no time during the winters of 1926–27 and 1927–28 was the insect in contact with temperatures which could be considered lethal on the basis of the laboratory tests recorded in Tables 42 to 47. Populations in the field in the fall of 1926 were generally small; but even in the few places where relatively high populations were present, it was extremely difficult to find the insect in the spring of 1927. The overwintering populations in the winter of 1927–28 were very high and remained so during the entire winter. From the standpoint of temperature, however, these two seasons differed only with respect to air temperatures.

The two "cold snaps" of the winter of 1926–27 were separated by a period during which active temperatures occurred as well as snow and rain. There are definite indications in the data to the effect that this combination of weather conditions may have had some effect; but if it did, the lethal temperatures for *E. tenellus* must have been raised in the meantime, since there is nothing in the temperature data for the soil-surface position to indicate that lethal temperatures prevailed, if the data obtained in the laboratory can be used as the criterion. Since for three winters the soil-surface temperatures have never reached those experimentally determined as lethal, it is improbable that direct action of low temperature, either of extremely low temperature for a short time or of moderately low temperature for

a longer period, is ever responsible for eliminating the overwintering *E. tenellus*.

That there is a relationship between low standard-shade temperatures and leaf-hopper attack the succeeding season is clear from a study of the past records, and field observations during three winters have indicated that there is a difference in survival, according as the winter is mild or severe, as judged by standard-shade conditions.

THE ECONOMIC APPLICATION OF THE DATA

PREDICTION OF INSECT OUTBREAKS

Where control measures have been found unsatisfactory or have not been found at all, the possibility of predicting outbreaks of economic insects has often been considered. In some instances preparations might be made so that an outbreak could be better handled if advance information were available. A recent example of both types is to be found in Seamans's (*24*, *25*) papers on forecasting outbreaks of the pale western cutworm and the army cutworm in Alberta. In the case of the former, a forecast would permit necessary cultural practices to be followed in the preceding fall, while in the latter case, preparations could be made to deal with the outbreak when it occurred. De Jong (*21*) reports that in Holland it was possible to forecast the occurrence of a number of tipulid species in five out of six years.

Cook has made important contributions to the literature of forecasting, first in his papers on distribution (*11*, *13*) and second in his papers on forecasting outbreaks of the pale western cutworm (*Porosagrotis orthogonia* Morr.) (*14*, *15*).

His most recent paper (*15*) is an attempt to estimate probabilities of certain weather conditions occurring. If long-range weather forecasting can be achieved, predicting of insect outbreaks will be much simplified.

Cook's paper on Climatic Variations and Moth Flight at Bozeman, Mont. (*12*), is of value to forecasting because it discusses the ebb and flow of entire insect faunas and the relation of this ebb and flow to climatic variations.

Both Seamans and Cook propose the use of the factor of rainfall as a basis for forecasts of pale western cutworm outbreaks. Seamans (*24*) uses the number of wet days in May and June, a wet day being defined as one with 0.25 inch of precipitation or more. Cook (*14*, *15*) uses the total rainfall in May, June, and July, and lays emphasis on the importance of soil moisture as the critical factor. De Jong (*21*) uses quantitative data on the insect populations.

In this bulletin climatic factors are referred to as requiring study in order that the effect of periods of drought may be properly evaluated.

PREDICTING OUTBREAKS OF EUTETTIX TENELLUS IN CENTRAL-SOUTHERN IDAHO

The fact that *Eutettix tenellus* is unquestionably a migratory insect makes forecasting an extremely difficult matter and limits forecasting by methods considered in this bulletin to those beet-growing areas which are contiguous to permanent breeding grounds of the insect. It is quite within the realm of possibility that data could be obtained on the insect in dispersal areas and the chances of migration to any particular place worked out on a basis of probability, but up to the

present time no extension of the predicting service has been attempted under such conditions. The possibility of an area being contiguous to a permanent breeding ground and yet subject, on occasion, to a migration from a distance is also to be considered. The migrations from a distance would unquestionably be a fruitful source of error unless the dispersal area was definitely known and continuous observations were taken thereon.

The beet-growing area bounded by Buhl, Idaho, on the west and Declo, Idaho, on the east lies contiguous to a permanent breeding ground. This statement is supported by the following observations:

(1) Damage is proportional to distance from the desert areas, irrespective of compass point. This is of course much more obvious in a year of slight damage, but it is nevertheless true even in the years of most severe damage.

(2) Some damage occurs every year in isolated localities closest to the greatest concentration areas in the contiguous breeding grounds.

(3) Local weather conditions are closely associated with local outbreaks.

Table 34 is a detailed statement of contracted and harvested areas, together with yields per acre. From this table it is evident that 1919, 1924, and 1926 were years of very severe outbreaks throughout the entire territory. There is evidence in the record of moderately severe damage in 1917 in the Twin Falls-Jerome area and severe damage in 1921 in the same area. Burley in 1917 lost a considerable percentage of its acreage, but the average yield was fair. In the same place in 1921 the acreage lost was slight, but tonnage was such that the crop was not profitable. On the other hand, the Burley district in 1925 yielded only an indifferent tonnage. The Oakley district, which borders on that of Burley, has a most unpromising record, only 3 years out of 13 having fair to good yields.

TABLE 34.—*Acreage and yields of beets in stated years in the Twin Falls, Jerome Burley, Oakley, and Paul districts, Idaho*

Year	Twin Falls and Jerome [1]			Twin Falls [1]			Jerome [1]		
	Area contracted	Area harvested	Average yield per acre	Area contracted	Area harvested	Average yield per acre	Area contracted	Area harvested	Average yield per acre
	Acres	*Acres*	*Tons*	*Acres*	*Acres*	*Tons*	*Acres*	*Acres*	*Tons*
1916	6,102	5,321	12.13						
1917	7,985	5,860	10.91						
1918	3,817	3,254	11.88						
1919	6,107	4,695	7.65						
1920	5,760	4,722	11.58						
1921	7,655	6,066	7.97						
1922				1,743	1,684	14.36	378	351	12.98
1923				3,710	3,623	14.95	973	945	11.24
1924				7,719	3,065	5.55	1,085	48	1.66
1925				3,291	3,027	15.31	874	818	11.17
1926				2,570	282	6.01	324	139	4.42
1927				5,035	4,333	16.95	1,495	1,479	11.27
	Burley			Oakley			Paul		
1916	8,960	6,360	8.75	1,118	649	6.71			
1917	3,348	2,708	11.0	792	635	7.54	5,745	4,249	8.99
1918	2,772	2,333	11.38	477	375	10.75	4,513	3,636	10.39
1919	5,058	4,175	4.91	821	512	2.67	7,196	3,460	6.32
1920	4,711	4,248	9.61	282	206	6.24	4,957	4,156	8.05
1921	4,408	4,287	10.21	887	742	8.12	4,987	3,870	9.46
1922	3,350	3,031	11.77	437	298	9.95	[2] 2,745	[2] 1,995	13.05
1923	5,839	5,491	14.15	570	478	14.19	[2] 5,070	[2] 4,700	13.24
1924	6,617	4,282	5.23	909	0	0	[2] 7,650	[2] 3,423	6.13
1925	3,504	3,408	10.57	434	250	7.49	[2] 4,039	[2] 3,406	11.81
1926	[2] 1,870	[2] 556	5.76	([3])	([3])	([3])	[2] 2,014	[2] 1,048	6.34
1927	[2] 1,785	[2] 1,639	14.11	([3])	([3])	([3])	[2] 2,017	[2] 1,894	14.76

[1] Records for Twin Falls and Jerome were not kept separate before 1922.
[2] Data for Oakley are included in data for Burley.
[3] Including data for Eden and Hazleton districts.

The records of individual growers indicate two important points, (1) that certain growers rarely or never sustain cash losses, and (2) that even in the years of high average yields some growers sustain losses. Table 35 illustrates this for three good beet years. On the other hand, according to the records of beet yields of the 1926 season in the Burley and Rupert districts, an occasional good crop is harvested even under most severe curly-top conditions.

TABLE 35.—*Acreage harvested in the Twin Falls, Burley, and Paul districts for three good beet years, 1923, 1925, and 1927, arranged according to yield*

Yield per acre	Twin Falls			Burley			Paul		
	1923	1925	1927	1923	1925	1927	1923	1925	1927
Tons	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
2	31	6	0				99	46	0
4	18	10	25	100	21	11	119	120	7
6	111	230	103	91	108	77	292	267	57
8	295	300	140	196	380	45	464	513	123
10	371	548	292	406	552	114	485	498	96
12	519	371	415	667	572	250	665	787	287
14	805	454	370	1,131	663	332	635	549	260
16	907	604	678	1,188	730	278	488	317	207
18	2,574	803	805	1,041	393	203	403	180	378
20	384	417	686	479	135	176	226	73	266
22	132	153	627	259	32	128	64	49	117
24	58	100	320	66	7	10	70	17	38
26	34	11	88	44	2	7	32	0	30
28	14	6	92	57	6		7	7	8
30	9	0	0	14	0	4	0	4	2
32	0	0	17	0	0	0	0	0	0
34	92	0	0	0	0	0	0	0	3
36	0	0	0	0	0	0	0	0	6

The area served by the three factories, Twin Falls, Paul, and Burley, is approximately 80 miles long and of very irregular width. The Oakley territory serving the Burley factory extends southward for approximately 20 miles in a narrow strip. The records of yields in Tables 34 and 35 are significant in that they suggest that even an area as small as this is not entirely homogeneous with respect to leaf-hopper damage.

The localities in this area differ with respect to economic conditions, and this factor is a significant one. Land values are higher in the Twin Falls district than in any other. There the standard of agricultural practice is extremely high, and it is the opinion of agriculturists competent to judge that for beets to maintain themselves in the face of competition with other crops, average yields must not fall below 13 tons per acre, with average sugar content. In the Burley, Paul, Oakley, and Jerome districts the standard of farming is not so high, neither is the value of land, so that average yields of from 11 tons per acre upward would probably maintain the crop's competitive status. This of course depends on the vagaries of the market for other crops, particularly potatoes.

In the predictions issued no distinction has been made between the Burley-Paul and Twin Falls-Jerome districts, and in 1927 the information was made available to Oakley farmers also, but with the added precaution of calling their attention to the unfavorable record of the district.

THE BASIS FOR PREDICTION IN THE TWIN FALLS-RUPERT DISTRICT

The study of the desert environment of the insect led to a rather clear conception of the rôle played by the environment in the economy of the insect. It was evident that if the host-plant succession should be maintained during the summer without serious interruption, huge populations of the insect would develop before winter set in. This maintenance of the food supply has been found to be related to certain factors of the external environment—precipitation, temperature, wind, and evaporation; while soil moisture, cell-sap concentration, and the maturity of the plants have served as indices of the combined effects of the factors just mentioned. The types of season, with their typical environment complexes associated with high and low fall insect populations, are thus known. From the practical entomological standpoint the quantitative data on the fall populations are sufficient, but the beet-sugar industry of course is interested in the development of the desert environment, since the data are of assistance in formulating plans a long time ahead of actually putting them into effect. For instance, an extremely hot, dry summer, eliminating most of the host plants on the desert breeding grounds, would indicate favorable prospects for the succeeding year and would justify advancing the contracting campaign two or three months.

Hibernation studies, supplemented by constant field observations in the desert areas during the winter, have established under what winter conditions the resistance of the hibernating populations is great or small. These data are of the greatest importance for forecasting probable leaf-hopper conditions, since the economics of the situation require that advice to be useful as a guide to planting be issued not later than March 1. It is evident from the winters of 1925–26 to 1927–28 that periods of below-zero weather very much reduce hibernating populations. The size of the populations entering hibernation is of course a moot point. There are roughly four possible combinations which may be encountered: (1) A high insect population entering hibernation followed by a mild winter; (2) a high insect population entering hibernation followed by a severe winter; (3) a low insect population followed by a mild winter; and (4) a low insect population followed by a severe winter.

The first is the most dangerous condition. The outbreak of 1926 followed such a condition, as did that of 1928. The second is dangerous, since expectancy of freedom from trouble the ensuing year depends on the severity of the winter. No record is available that the third case ever happened, but if the overwintering population is initially low enough, an abnormally mild winter would be necessary to reduce expectancy of a good beet year.

The fourth case is most desirable. The crop year of 1927 followed such a condition. It is true that the winter was not so severe as has happened, but initial overwintering populations were so low as to reduce dependence on this factor to a considerable extent.

With this as the basis for a working hypothesis, a study was made of the records back to 1919, the first year when the damage due to the insect was clear-cut. The daily maximum and minimum temperatures were plotted for the period from December 1 to May 31. (Figs. 13 to 22.) Insets in the figures are records of the monthly precipitation from October to the end of February, while daily

precipitation records for the period from September 1 to February 28 are plotted underneath the temperature records.

Studies of the fall and winter precipitation have been unproductive of useful results; however, the hibernation studies reported earlier in this bulletin indicate that precipitation may be of some importance, even though the conditions governing its effect are not yet understood.

DISCUSSION OF CLIMATOLOGICAL DATA AND BEET YIELDS, 1918–1926

Winter of 1918–19 (fig. 13): In 1919 the crop was grown at a general loss throughout the entire area now under consideration.

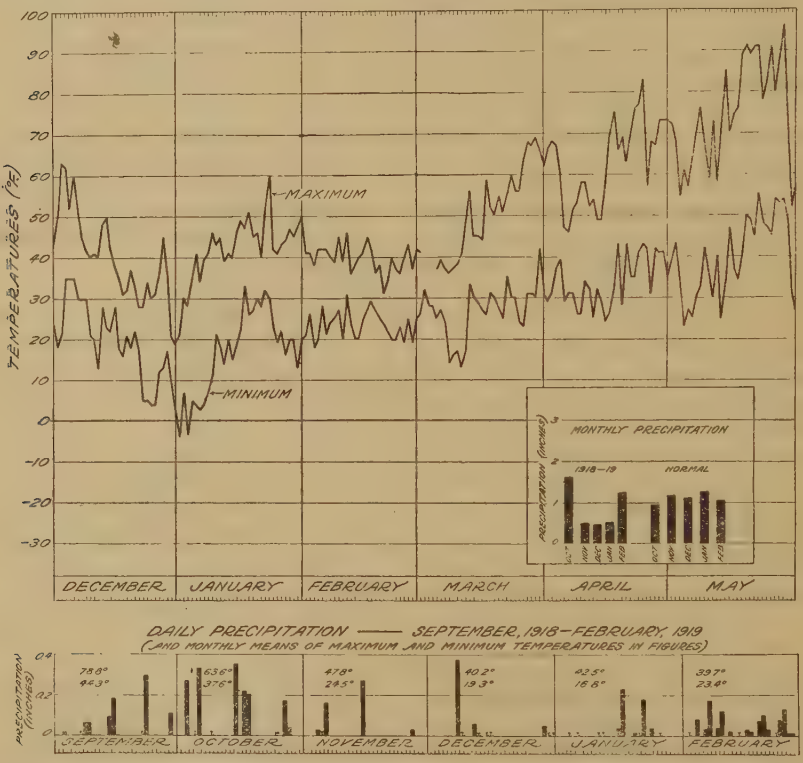


FIGURE 13.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1918–19

No data on insect populations were available until the fall of 1922, but it is evident from Figure 13 that the winter was mild. The line on the figure indicates that the zero-degree-Fahrenheit level was barely crossed only during one short period in January.

Winter of 1919–20 (fig. 14): The beet yield in 1920 was fair. (It should be remembered that, as far as the Twin Falls district is concerned, improved agricultural supervision from 1922 on had much to do with the improved average yields.) This winter was unusual in that below-zero weather occurred in two months, and the February record is missing. Two days in November showed minimum temperatures of −7° and −8° F. This type of winter is undoubtedly favorable for reducing hibernating populations, since it involves low

temperatures alternating with short periods of activity on the part of the insects.

Winter of 1920–21 (fig. 15): Beets in the eastern end of the district in 1921 yielded an average tonnage close to that required to pay cost of production. On the basis of the winter (but without data on hibernating populations) a prediction would have been in order for a bad beet year. The result might have been a subject of difference of opinion in view of the yield in the eastern end of the district. The spring and early summer of 1921 were characterized by very heavy rainfall which undoubtedly did much to bring the yield in

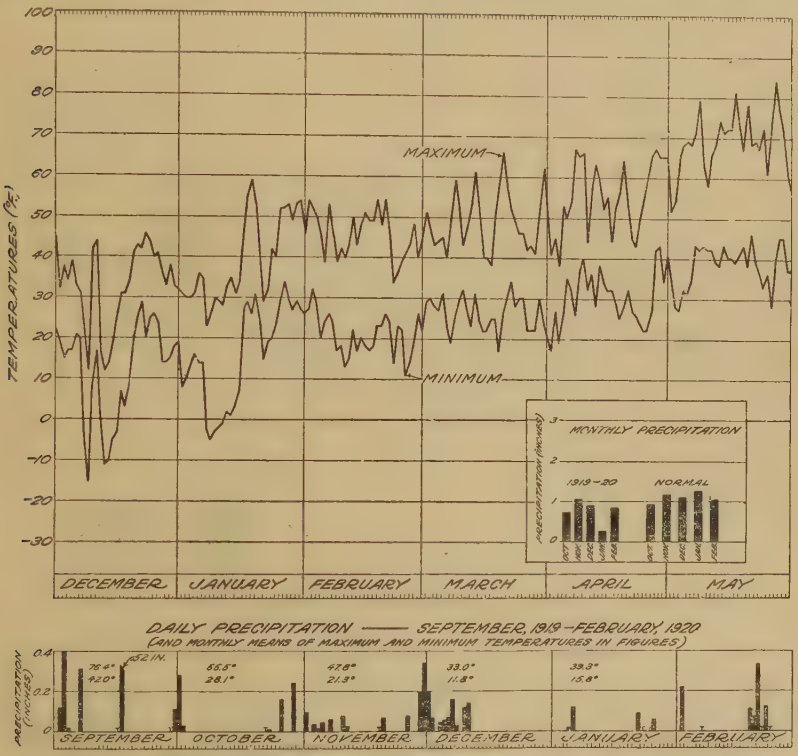


FIGURE 14.—Daily temperatures (December to May) and precipitation (September to January) at Twin Falls, Idaho, season of 1919–20

the eastern end up to a point where it could not at any rate be described as a failure even though disappointing. The fact that in the western half of the district over 2,000 acres were abandoned and an average yield of 7.97 tons per acre was obtained on the balance would, in the opinion of the writer, have justified a prediction for a bad beet year. The effect of the yields obtained is seen in the fact that, in spite of a severe winter in 1921–22, acreage was materially reduced even in the eastern end the following year. This is perhaps the best commentary on what the farmers in the eastern end thought of the yields obtained in 1921.

Winter of 1921–22 (fig. 16): This winter was characterized by one very severe drop in temperature. This type of winter has occurred only twice in the 10 years covered by these figures. A high yield of

beets was obtained in 1922. There are, however, some valuable data on the date of migration and the appearance of disease during this season available in a report, embodying the results of a summer's work in the area, made by Asa C. Maxson to the Amalgamated Sugar Co. Maxson reported that a migration occurred between June 17 and June 26 and that considerable disease was to be found in the fields at harvest time. No quantitative data on insect populations in beet fields are available.

Winter of 1922–23 (fig. 17): Judging from Maxson's report, it is very likely that high populations entered hibernation. The winter

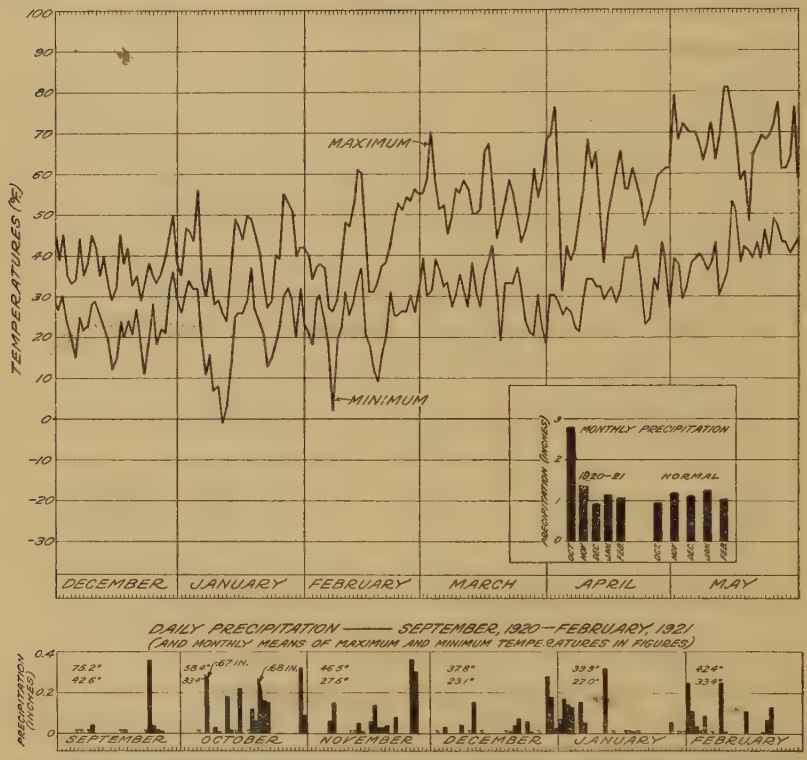


FIGURE 15.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1920–21

is interesting in that it was characterized by a drop in temperature just below zero, a long period when temperatures favorable for activity prevailed, followed by a period of 10 days with minimum temperature below zero. This also is the only winter when the fall and winter precipitation was probably a factor that can be explained. As has been described in the section on the insect and its host plants, a prolonged dry fall will force the insect to normally unfavorable hosts. The lack of precipitation prior to the 1923 beet season was most pronounced, since from September 1 to the end of March there was a minus deviation from the normal of 4.36 inches. A third point in favor of beet prospects for 1923 was the copious rainfall in April, May, and June. The yield was uniformly satisfactory throughout the district.

Winter of 1923–24 (fig. 18): It will be observed that the winter minimum touched zero only on one occasion, the minima for the winter being very high. The copious rains during the summer of 1923 imply that without much question a high initial population prevailed on the desert breeding grounds in the fall.

Winter of 1924–25 (fig. 19): Maxson again visited the area for a short time in 1924. His report indicates very high desert populations. The winter was characterized by one period of pronounced below-zero weather. The writer's observations commenced in the

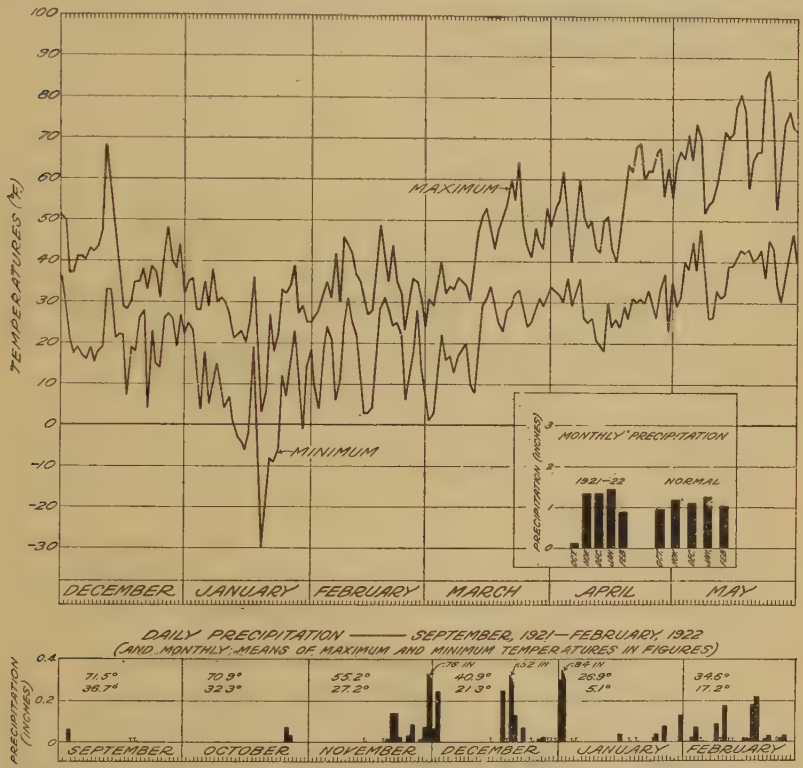


FIGURE 16.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1921–22

early summer of 1925. The migration into the beet fields was difficult to determine with accuracy, but it evidently occurred the first few days of July. Prior to that time, as in 1922, occasional diseased beets could be found. The majority of the beets were large at the time the migration occurred, and serious damage was limited to late plantings or poor stands.

A hailstorm early in July contributed to damage in the locality visited by the storm, since leaves were stripped off and the environment opened up in such a manner as to favor very much increased activity on the part of the insect. By the end of the season it was difficult to find a single beet not showing some symptoms of the curly-top disease, but the yield in the Twin Falls district was the highest recorded up to that time. The yield in the Burley district

was disappointing. There was unquestionably a good deal of severe damage, but how much of this was due to indifferent farming as an important secondary cause is difficult to determine. Undoubtedly this factor operated to a considerable extent. The farmer who has a poor or late stand of beets is likely to neglect the crop if any other unfavorable factor enters in. This is particularly true if the unfavorable factor is *Eutettix tenellus*.

Winter of 1925–26 (fig. 20): This was an extremely mild winter. The evenly distributed rainfall of 1925 resulted in a most favorable host-plant succession and high populations were distributed evenly over the whole breeding-ground area. Overwintering was very suc-

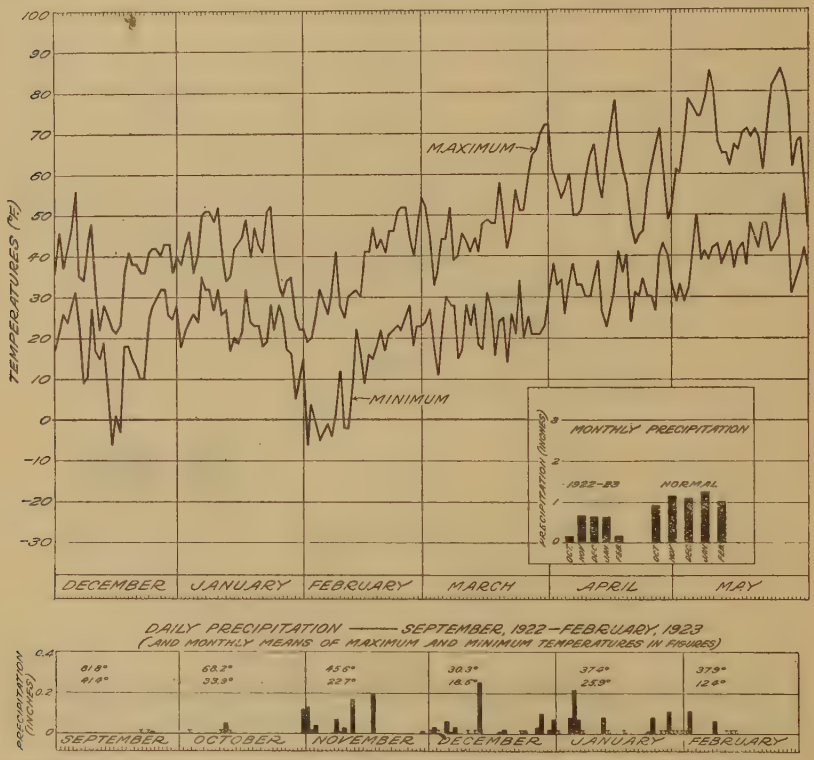


FIGURE 17.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1922–23

cessful, as observations at regular intervals throughout the winter revealed. The spring season opened up very early, with the result that, in addition to a very large overwintering population, the first generation had appeared by May 1. A heavy infestation occurred between the 3d and 6th of May and the insect evidently continued to drift into the fields for some time afterwards until populations were so high that counts could no longer be made with any accuracy. By the end of May the populations varied from 10 to 150 leaf hoppers to 100 beet plants, while obviously diseased beets (that is, plants apparently so diseased that careful diagnosis was not necessary) amounted in some cases to 75 per cent of the crop.

THE LEAF HOPPER PREDICTION OF 1927

Owing to the extremely dry and hot summer of 1926 the host-plant succession in the breeding grounds was seriously disturbed, so that only a few favorable localities developed high leaf hopper populations during the fall. These were so few and far between that it was felt that the factor of low initial hibernation population of itself was sufficient to give reasonable assurance that the year 1927 would be favorable for beets. When below-zero weather occurred in December on two occasions, separated by maximum temperatures above 40° F. (fig. 21), and with the previous records and studies as guides, it was

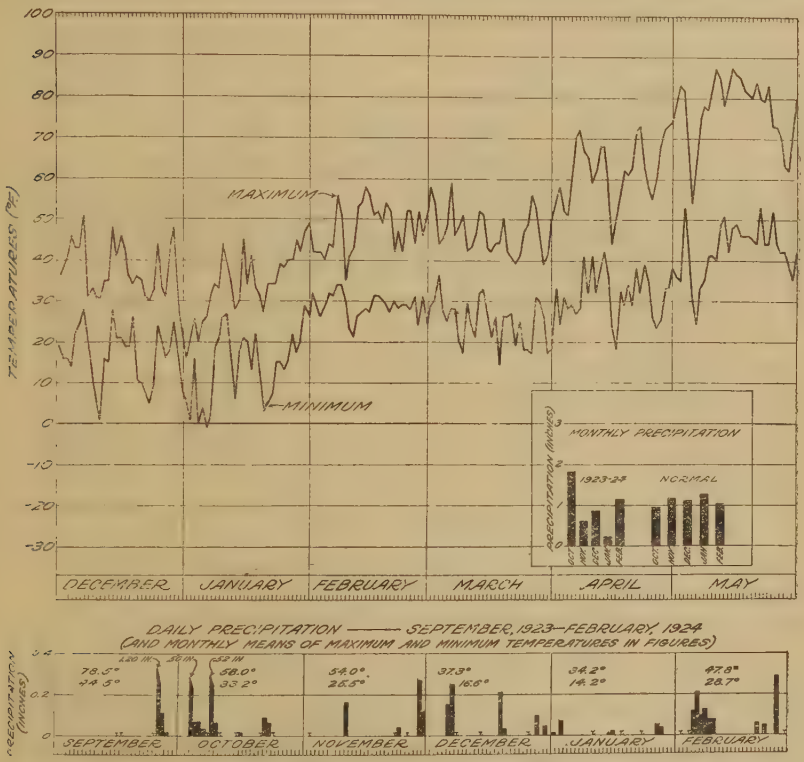


FIGURE 18.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1923–24

decided to initiate the release of advice which might be used as a guide to planting. The following letter was addressed to farmers in the beet-growing area extending from Rupert (the Paul factory district) to Buhl, Idaho, including the north-side irrigation section centering in Jerome, Idaho:

BOX 1100, TWIN FALLS, IDAHO,
January 28, 1927.

DEAR SIR:

The United States Department of Agriculture has, for some time past, been conducting studies of the white fly in this region. One of the objects of this study has been to build up sufficient information to enable its officers to make forecasts as to the sugar-beet prospects.

These studies have shown that the white fly breeds on the desert and that it is necessary for rainfall to be reasonably plentiful on the desert before the food plants of the insect are present in sufficient quantity for the breeding up of large popula-

tions of the insect. These large populations are necessary before serious damage can be expected in the beet fields.

The next thing necessary is a winter which will permit the bugs to winter over successfully. Past records show that severe winters have never been followed by bad fly years. Just why this is, is not known but it is true nevertheless, so far.

The populations on the desert in the fall of 1925 were very large; the winter was one of the mildest on record. This combination resulted, as you all know, in one of the most severe attacks ever experienced in this area. On the other hand, the populations during 1926 were very much reduced by the very early drying up of the desert. Our records show that not only were the numbers of bugs very

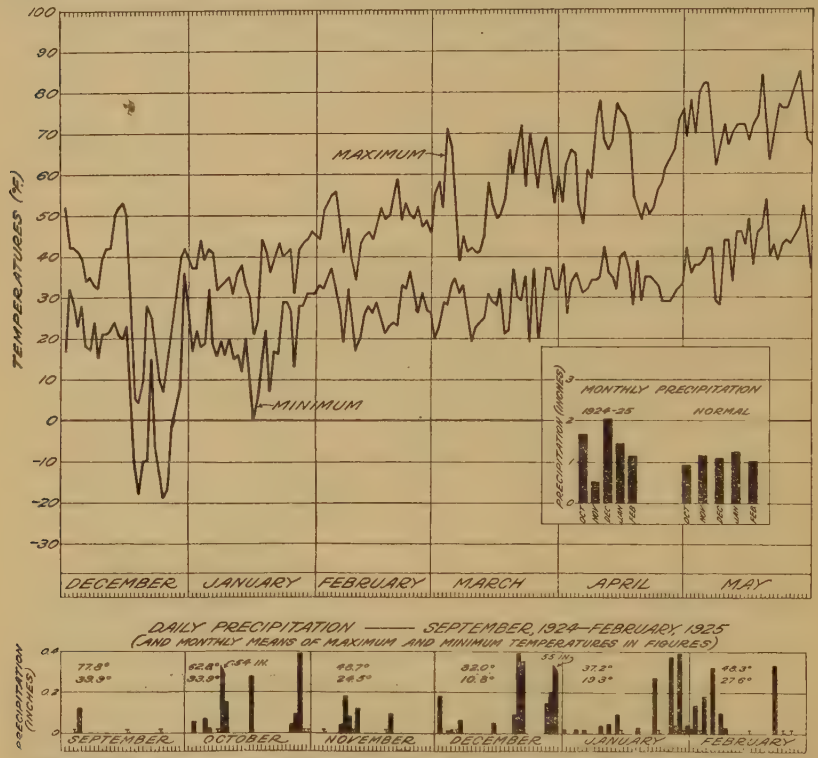


FIGURE 19.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1924–25

much reduced, but the areas on which these bugs were to be found were even more reduced.

This is the principal reason for our optimism for the coming season. In addition, the winter has been a very satisfactory one from the beet grower's standpoint so that from both points of view the prospects for 1927 are very fine.

This opinion is of course subject to human error. A great many details remain to be worked out before all the factors involved in a forecast can be understood and used with confidence. Such data as we have, however, all point to a good year for 1927. Such opinion is entirely independent of outside influence, and farmers may feel assured that this office will put the facts into their hands irrespective of whether the news is good, bad, or indifferent. It is hoped that this forecasting service will prevent the losses of past years and at the same time give farmers confidence for those years when the prospects are good.

This letter is the only written official statement thus far on the forecast for 1927 and is written to prevent misunderstanding due to incomplete press reports or possible misquotations of verbal addresses.

Yours very truly,

WALTER CARTER,
Associate Entomologist in Charge
Beet Leaf-hopper Investigations.

It will be observed from this letter that some care was exercised in presenting a condensed summary of the data as they existed. This was deemed necessary in order that beet growers could be individually informed. It was desirable also because the beet growers in this district have had a long and varied experience with the insect, which could be used in a consideration of the entomological data made available to them. In this way the matter of making a decision as to whether or not to plant beets was obviously in their own hands, and thus was maintained the traditional policy of the Depart-

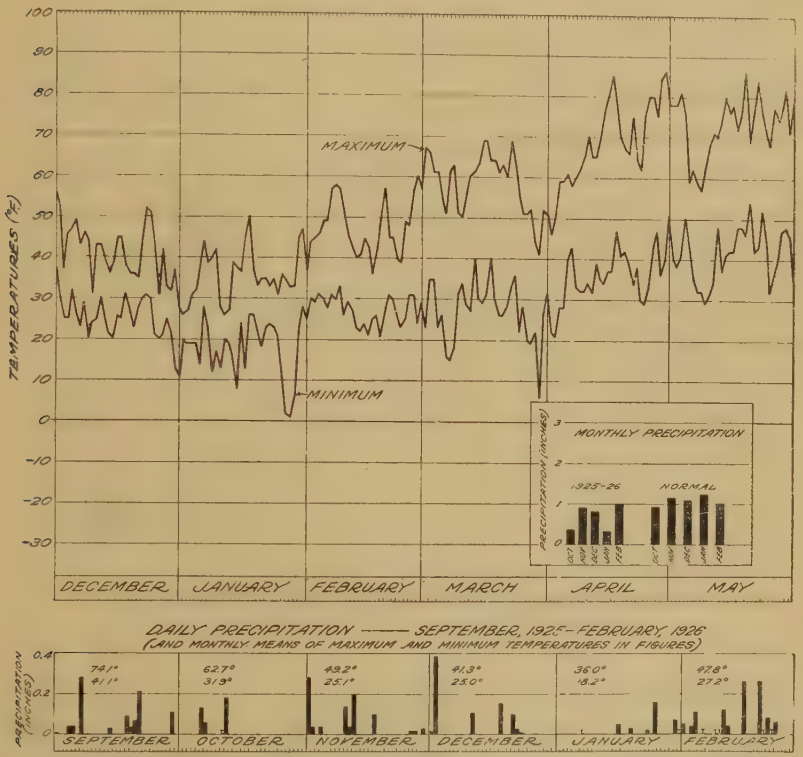


FIGURE 20.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1925–26

ment of Agriculture in limiting its service under such circumstances to making data available.

The prediction as to expected leaf-hopper conditions had considerable effect. Reference to Table 34 will show the acreage trend in the past. The highest acreages nearly always occurred in the years of greatest damage. The winter of 1925–26 was so mild that growers, drawing on their experience, were reluctant to plant beets, so that the usual increase in acreage following the good year of 1925 did not materialize in 1926. The low price of beets in 1925 was an additional factor of some importance.

The prediction in 1927 did much to initiate what is hoped will be a complete reversal of the past acreage trends. For the first time in the history of beet growing in that district the acreage was increased

following an unfavorable beet year. The yields per acre throughout the entire district included in the prediction were the highest on record. It was fortunate that the first year of prediction should have resulted in such yields, but such a record was not necessary, of course, to establish the success of the prediction for the favorable beet year in 1927. If a prediction for a favorable beet year is followed by a yield equal to the average obtained in previous good beet years the prediction can be considered successful. The criterion for the success of a prediction for an unfavorable beet year must neces-

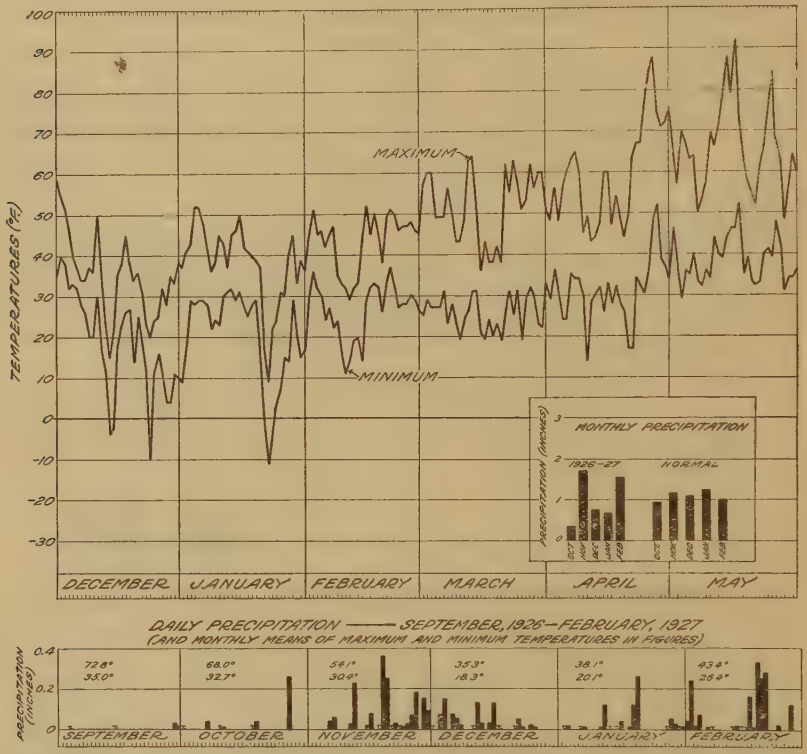


FIGURE 21.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1926–27

sarily be the minimum profitable yield for the district, economic factors being considered.

By June 1, 1927, it was evident that the initial spring populations on the desert breeding grounds were as low as was expected. Occasional specimens could be found after considerable searching, but it was not until the first brood was emerging that the insect became generally easy to find, and even then the populations were very small. The migration of June 13, therefore, was dramatic and alarming. The first thought was that the district had been subject to a long-distance migration, since the field populations seemed too great to be accounted for on the basis of the local insects. A thorough survey revealed the fact, however, that the beet-field populations varied directly with the distance from the local breeding grounds, and, generally speaking, were not of economic importance except in those

fields located very close to known localities of concentration in the breeding grounds. Two localities were, however, damaged quite severely. One was the Castleford district in the extreme west of the cultivated area, where all the beet fields were literally next door to the breeding grounds. The other was in a small section of irrigated land known as the Golden Valley district between Twin Falls and Burley. The first-named district was recognized as a danger spot even during the best possible year, and the few farmers who grew beets there were so informed. The writer had no knowledge of the Golden Valley district until by chance the beet fields were discovered. This

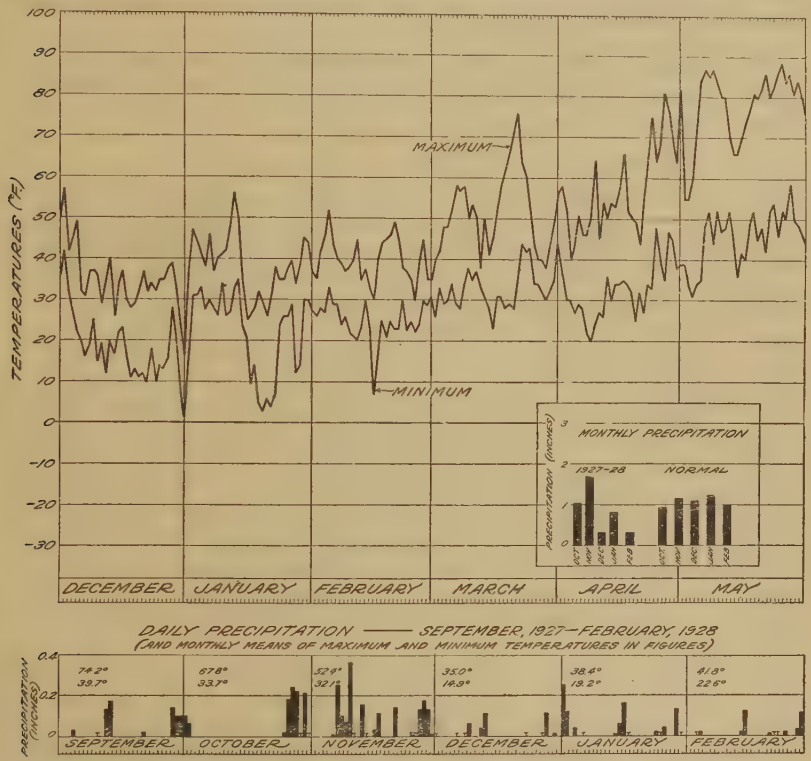


FIGURE 22.—Daily temperatures (December to May) and precipitation (September to February) at Twin Falls, Idaho, season of 1927–28

district is likewise in the very midst of a very large area of abandoned land, from which there was a very heavy migration of the insect into these fields, with resulting damage.

The experience was valuable because it demonstrated that even under the most favorable circumstances a migration might be expected during the summer some time after the emergence of the first brood.

The area of breeding ground is so great and the potential of the insect so high that even an extremely low initial population might develop to serious proportions when the first brood has emerged. Some reduction in yields therefore will probably always take place, but in those years when the first brood is necessary to the develop-

ment of economically dangerous populations, the beets have an excellent chance to acquire sufficient size to withstand an attack which, if it occurred a month earlier in the season, would cause serious losses. Generally, late beets suffer damage every year, sometimes so serious as to result in abandonment without harvesting.

Another point involved is the overwintering of the virus. Only 8 per cent of individual leaf hoppers taken from a field in the Castleford district over two weeks after the migration produced the disease, and only one individual had a normal incubation period; in the remaining cases the period was much prolonged.

The relationship between certain weather conditions during the winter and the severity, attenuation, or even the presence of the virus, is a moot question, and an answer to it might well be an important aid in explaining the undoubted relationship that exists between certain winter types and the succeeding year's beet crop.

THE LEAF HOPPER PREDICTION OF 1928

The winter of 1927–28 (fig. 22) must be classified as a mild winter. Much of the weather was disagreeable but not severe in the needed way. The fall populations were extremely high; *Eutettix tenellus* was found easily and in numbers throughout the winter. On March 1 the following notice was mailed to beet growers:

Sugar-Beet Prospect for 1928 for Area Between Rupert and Buhl Only

The present prospects are quite different from those of a year ago. Last fall was very favorable for the white fly's development, and very high populations were present over the entire area late last fall. It was realized that very severe weather would be necessary to eliminate sufficient numbers of the white fly to permit of a favorable forecast. While it is true that the winter has seemed severe to many people, it is unfortunately true that the kind of weather needed has not materialized up to this time. Large numbers of the insect can easily be found on the wild plants on any warm afternoon such as we have been experiencing.

The insects are active and feeding, and with normal weather conditions for the next two or three months, enormous populations of the fly can be expected on the desert areas; and past experience has shown that when this is the case, serious results follow.

With unusual weather—a very late spring and heavy precipitation during April, May, and June—the development of the fly on the desert may be held up for a time and the wild host plants kept in good condition longer than usual, perhaps permitting some fair yields of beets in fields well removed from the breeding grounds. This has no doubt happened before, it probably happened in 1921, and this possibility is the only thing we have to offset the decidedly unfavorable prospects for a good beet year, which we are faced with at the present time.

Undoubtedly, at worst, some patches of beets will make good yields, but we must forecast on the basis of what might be expected to happen on the average over the beet-growing area between Rupert and Buhl, including the north side tract, and this forecast is not applicable to any other beet-growing area. In this area all the indications at the present time are decidedly unfavorable.

Summary of Facts Concerning the White Fly for this Season

Information as at February 29, 1928

Very large numbers of the white fly went into hibernation for the winter;

The winter has not been severe enough to reduce these numbers sufficiently;

Large numbers of the fly can easily be found at the present time, active and feeding on the wild plants;

With normal weather conditions between now and the danger period, very large and dangerous populations of the insect can be expected;

An abnormally late spring with heavy precipitation during the spring and early summer months might delay the invasion for a time, and permit the best beets to make fair yields.

The Department of Agriculture does not presume to advise whether to plant, or not to plant, beets. It undertook, commencing with last year's forecast, to give farmers all the information available by the end of February each year, and it is in pursuance of that policy that this forecast is issued. Farmers who decide to plant, notwithstanding present indications, may feel free to call upon this office for further information which may become available between now and the time when they must decide whether or not to continue with the crop. All present indications, however, are distinctly unfavorable.

The very satisfactory yields of 1927 had put farmers into a state of mind very favorable to beet growing, and interest in the crop was intense. The Amalgamated Sugar Co., however, signed contracts only on condition that they were returnable to the farmer in the event that the prediction was for a favorable year. Many farmers refused to consider contracting until the prediction was issued, but in the Twin Falls district some 4,500 acres were contracted before the issuance of the March 1 statement. The attitude of these farmers toward prediction can be well judged by the fact that contracts for over 4,000 acres were returned to, and cancelled by, the signers. It is conservatively estimated that contracts would have been made for 10,000 acres if the prediction for 1928 had been for a good beet year.

In the Burley and Paul districts economic factors operated to the extent that about 50 per cent of the acreage for which contracts would have been made in the event that the prediction had been for favorable prospects, was signed for. This acreage (approximately 3,600) decreased to 3,200 acres planted. The heavy April and May rain, which these farmers were depending on, did not materialize, and less than 2,000 of the acres planted were thinned.

In the Twin Falls section occasional diseased beets could be found early in May, but by May 10 and 11 there was evidence of an initial migration. This population gradually increased, moving eastward until by the beginning of the last week of May the eastern limits of the Twin Falls factory district were included in the migration area. Disease symptoms appeared rapidly, so that by the end of May it was evident that the prediction so far as the Twin Falls section was concerned was fully justified. On the first of June a small field of beets near the Twin Falls factory was plowed up. Counts made just prior to the plowing revealed that 50 per cent of the beets were seriously affected.

The eastern end of the area (Burley and Paul districts) showed only occasional *E. tenellus* during May, though weather favorable to accurate observation was rare. By the middle of June there was evidence of the migration there, with up to 10 per cent of the plants showing disease. Two-thirds grown nymphs in the beet fields indicated the presence of *tenellus* in the fields for a considerable time previous.

The spring weather after the beets were up strongly favored the beets and was unfavorable to the rapid development of the insect. The desert breeding grounds by the end of May were generally in poor condition in the western end but were in excellent condition in the Burley and Paul districts. A heavy rain in early June and much cloudy weather still further favored the host plants, which on June 15 were still in excellent condition.

In spite of these factors adverse to the prediction, the prediction issued on March 1, that prospects for a good beet year were poor, was borne out.

The overwintering of the virus during the winter of 1927–28 was also of significance. As has been discussed in the section concerning host-plant relationships, the insect's principal fall host plant is *Salsola pestifer* (Russian thistle). In the fall of 1927 numerous tests were made of the virus-bearing of *E. tenellus* taken from this host plant for use in hibernation experiments, but not a single positive result was obtained, even with the use of 10 insects to 1 plant. When the winter survivors were removed from the cages in January and February, they were again tested and numerous positive results obtained, even though weather conditions at the time were not suitable to the development of the disease. Disease was easily transmitted to beets by *tenellus* captured in the field early in the spring. This evidence simply supported the prediction as issued on March 1, and the development of the disease in May, 1928, was complete confirmation of the expectancy for severe disease to which the early spring experiments on the virus-bearing of the insect led.

When a migration occurs which infests beet fields with dramatic suddenness, as in 1926, it is a relatively simple matter to determine what to do with the majority of the beet fields. In a year such as 1928 this would have been most difficult, in view of the fact that the influx was of a dribbling nature with a steady increase in population which required trained observers to recognize.

Thus the worst combination of circumstances that the beet industry could have had to face was avoided by the prediction and immense losses were prevented. The use of a large acreage of high-priced land and large cash outlays for labor were avoided by the farmer. The manufacturing side of the industry was saved the necessity of large expenditures for conditioning mills and was enabled to cut its overhead expense in many ways, although the closing down of three factories was a serious blow to the company.

PREDICTING THE TIME OF MIGRATION

To predict the time of migration is a most difficult thing to do with the data now available, but the development of accuracy in this connection will be extremely useful. The beginning of the influx was predicted with reasonable accuracy in the spring of 1928 on the basis of the data in Tables 6 and 39, but more types of seasonal conditions must be recognized before the information can be made available to the farming public. In the Twin Falls district such information would be of the greatest use in connection with planting dates for beans and other crops which are liable to injury from the insect (*5, 28, 30*). A proposed canning factory will no doubt suffer serious reverses if its planting program can not be intelligently planned.

THE BIOLOGICAL "X"

In all predictions of insect outbreaks it must be remembered that an amazingly complex situation is being dealt with, only a small portion of which is measurable or explainable. There is always an unknown quantity of considerable dimensions. In 1927 there were undoubtedly more insects in the beet fields than any of the data would lead one to expect. In 1928 the spring weather conditions

favored migration, but late rains and exceptionally favorable weather for beet growing subjected the prediction to an extremely severe test. In spite of these factors, however, the predictions for these two years were successful. Undoubtedly the biological "X" will become smaller as more complete information is accumulated. The success of the prediction, in spite of the operation of the unforeseen, leads to confidence in the soundness of the basic relationships on which the predictions are based. These are a study of the insect's environment and, on the basis of this, correlations between the environmental complex and the yield of sugar beets. In other words, there is every reason to believe that the relationship between insect and weather at the end of February will determine within rather narrow limits what the losses due to the insect will be at harvest time.

SEASONAL CHECKS ON THE PREDICTION

The prediction is issued at the end of February, but certain opportunities are available for checking up on later conditions. Populations can be determined by field observations early in March, and in case winter resistance is found to have been less than was expected there would still be time to warn growers.

The most difficult hypothetical case is the one where low fall populations are followed by a mild winter. In this case precipitation in the critical months of April, May, and June would probably determine the extent of the damage to a considerable degree. In view of the attitude of meteorologists toward long-range weather forecasting, an ecologist's attempts along that line are perhaps more recreational than useful. However, it is possible to examine the record of any one place and learn something of the probabilities of rainfall distribution for any particular period. Certainly this method should be thoroughly exhausted, even though its limitations are clearly recognized. Cook (*15*) has examined the rainfall record of regions liable to outbreaks of the pale western cutworm and has shown that there is a close connection between the chances of a single favorable year and the ability of *Porosagrotis orthogonia* Morr. to maintain itself at a place.

In the case of predicting outbreaks of *E. tenellus*, the probabilities for abnormal or subnormal precipitation in the three critical months are of great interest and possible usefulness in the event of encountering a population-winter relationship at the end of February which is inconclusive.

In Table 36 the precipitation which actually occurred at Twin Falls is compared with the normal for each month; from this the deviation is obtained and accumulated deviations are calculated. The rainfall year is considered as from September 1 to the end of August the following calendar year. Figure 23 graphically represents the monthly precipitation for 10 seasons. The accumulated deviations from the normal are shown on the charts and the winter types are indicated in the legend. This figure summarizes conditions with respect to precipitation at Twin Falls for the period covered by Figures 13 to 22.

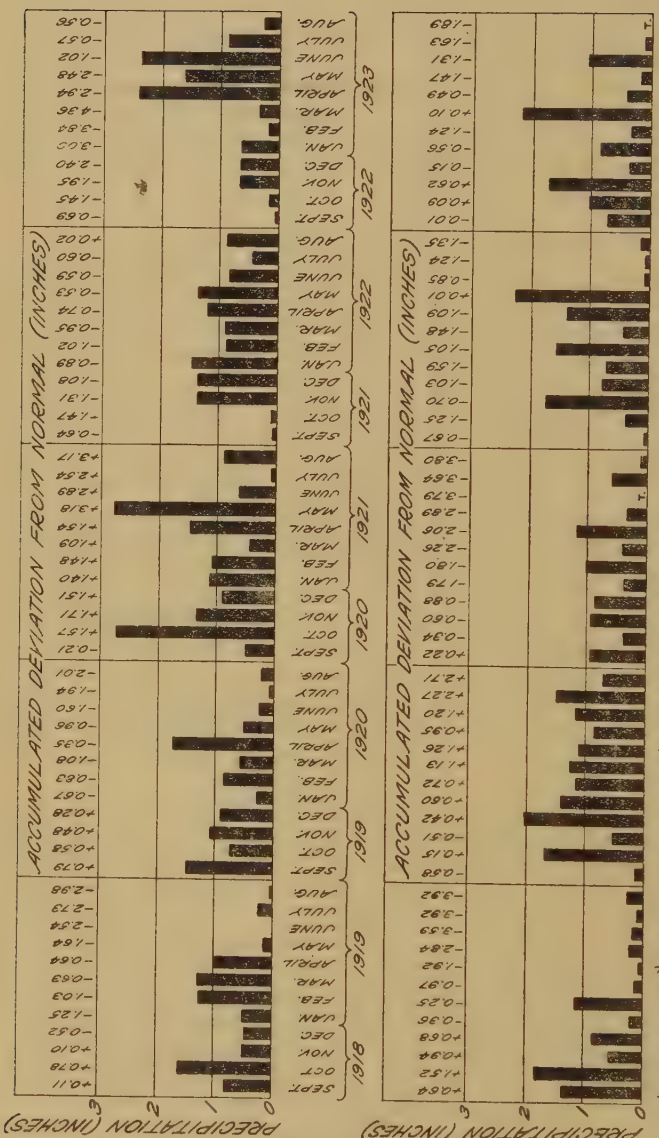


FIGURE 23.—Monthly precipitation and deviations from normal, at Twin Falls, Idaho, September, 1918, to August, 1928, inclusive. The winter conditions were characterized as follows: 1918–19, mild; 1919–20, severe; 1920–21, mild; 1921–22, very severe; 1922–23, moderately severe; 1923–24, mild; 1924–25, very severe; 1925–26, mild; 1926–27, severe; 1927–28, mild

TABLE 36.—*Precipitation at Twin Falls, Idaho, seasons of 1905–6 to 1927–28, inclusive*

Season and month	Normal	Actual	Deviation from normal	Accumulated deviation from normal
1905–6	*In.*	*In.*	*In.*	*In.*
September	0.70	0.15	−0.55	−0.55
October	.93	0	−.93	−1.48
November	1.17	.09	−1.08	−2.56
December	1.10	1.20	+.10	−2.46
January	1.24	1.01	−.23	−2.69
February	1.01	1.10	+.09	−2.60
March	.84	1.99	+1.15	−1.45
April	.99	.24	−.75	−2.20
May	1.14	1.58	+.44	−1.76
June	.90	2.72	+1.82	+.06
July	.43	.09	−.34	−.28
August	.26	.10	−.16	−.44
1906–7				
September	.70	.11	−.59	−.59
October	.93	.06	−.87	−1.46
November	1.17	1.00	−.17	−1.63
December	1.10	1.71	+.61	−1.02
January	1.24	1.34	+.10	−.92
February	1.01	2.90	+1.89	+.97
March	.84	4.80	+3.96	+4.93
April	.99	.97	−.02	+4.91
May	1.14	.93	−.21	+4.70
June	.90	2.43	+1.53	+6.23
July	.43	.15	−.28	+5.95
August	.26	.43	+.17	+6.12
1907–8				
September	.70	.70	0	0
October	.93	1.19	+.26	+.26
November	1.17	.72	−.45	−.19
December	1.10	1.79	+.69	+.50
January	1.24	.28	−.96	−.46
February	1.01	.10	−.91	−1.37
March	.84	.03	−.81	−2.18
April	.99	.12	−.87	−3.05
May	1.14	1.88	+.74	−2.31
June	.90	1.75	+.85	−1.46
July	.43	.49	+.06	−1.40
August	.26	.60	+.34	−1.06
1908–9				
September	.70	.82	+.12	+.12
October	.93	1.88	+.95	+1.07
November	1.17	.46	−.71	+.36
December	1.10	.16	−.94	−.58
January	1.24	3.49	+2.25	+1.67
February	1.01	1.25	+.24	+1.91
March	.84	.44	−.40	+1.51
April	.99	.34	−.65	+.86
May	1.14	.49	−.65	+.21
June	.90	.08	−.82	−.61
July	.43	1.28	+.85	+.24
August	.26	.30	+.04	+.28
1909–10				
September	.70	1.54	+.84	+.84
October	.93	.73	−.20	+.64
November	1.17	3.95	+2.78	+3.42
December	1.10	1.63	+.53	+3.95
January	1.24	1.35	+.11	+4.06
February	1.01	1.61	+.60	+4.66
March	.84	.16	−.68	+3.98
April	.99	.73	−.26	+3.72
May	1.14	.52	−.62	+3.10
June	.90	.06	−.84	+2.26
July	.43	.12	−.31	+1.95
August	.26	(1)	−.26	+1.69
1910–11				
September	.70	.95	+.25	+.25
October	.93	.48	−.45	−.20
November	1.17	1.90	+.73	+.53
December	1.10	1.13	+.03	+.56
1910–11				
January	1.24	2.92	+1.68	+2.24
February	1.01	.74	−.27	+1.97
March	.84	.49	−.35	+1.62
April	.99	.43	−.56	+1.06
May	1.14	1.74	+.60	+1.66
June	.90	.83	−.07	+1.59
July	.43	.05	−.38	+1.21
August	.26	.04	−.22	+.99
1911–12				
September	.70	.10	−.60	−.60
October	.93	1.46	+.53	−.07
November	1.17	1.88	+.71	+.64
December	1.10	.78	−.32	+.32
January	1.24	2.29	+1.05	+1.37
February	1.01	.64	−.37	+1.00
March	.84	1.29	+.45	+1.45
April	.99	1.68	+.69	+2.14
May	1.14	.63	−.51	+1.63
June	.90	.46	−.44	+1.19
July	.43	.48	+.05	+1.24
August	.26	.16	−.10	+1.14
1912–13				
September	.70	.30	−.40	−.40
October	.93	2.89	+1.96	+1.56
November	1.17	1.10	−.07	+1.49
December	1.10	.54	−.56	+.93
January	1.24	1.19	−.05	+.88
February	1.01	.21	−.80	+.08
March	.84	.65	−.19	−.11
April	.99	.53	−.46	−.57
May	1.14	.75	−.39	−.96
June	.90	2.54	+1.64	+.68
July	.43	1.50	+1.07	+1.75
August	.26	.17	−.09	+1.66
1913–14				
September	.70	2.09	+1.39	+1.39
October	.93	1.35	+.42	+1.81
November	1.17	2.09	+.92	+2.73
December	1.10	1.77	+.67	+3.40
January	1.24	2.13	+.89	+4.29
February	1.01	.65	−.36	+3.93
March	.84	.02	−.82	+3.11
April	.99	1.51	+.52	+3.63
May	1.14	.61	−.53	+3.10
June	.90	.75	−.15	+2.95
July	.43	.32	−.11	+2.84
August	.26	0	−.26	+2.58
1914–15				
September	.70	1.08	+.38	+.38
October	.93	1.45	+.52	+.90
November	1.17	.01	−1.16	−.26
December	1.10	.49	−.61	−.87
January	1.24	.79	−.45	−1.32
February	1.01	.70	−.31	−1.63
March	.84	.30	−.54	−2.17
April	.99	.64	−.35	−2.52
May	1.14	3.13	+1.99	−.53
June	.90	.27	−.63	−1.16
July	.43	.25	−.18	−1.34
August	.26	.02	−.24	−1.58
1915–16				
September	.70	1.54	+.84	+.84
October	.93	0	−.93	−.09
November	1.17	1.31	+.14	+.05
December	1.10	1.58	+.48	+.53
January	1.24	1.47	+.23	+.76
February	1.01	2.05	+1.04	+1.80
March	.84	1.09	+.25	+2.05
April	.99	1.16	+.17	+2.22

[1] Trace.

TABLE 36.—*Precipitation at Twin Falls, Idaho, seasons of 1905–6 to 1927–28, inclusive*—Continued

Season and month	Normal	Actual	Deviation from normal	Accumulated deviation from normal
	In.	*In.*	*In.*	*In.*
1915–16				
May	1.14	0.80	−0.34	+1.88
June	.90	.08	−.82	+1.06
July	.43	.35	−.08	+.98
August	.26	.01	−.25	+.73
1916–17				
September	.70	0	−.70	−.70
October	.93	1.30	+.37	−.33
November	1.17	.76	−.41	−.74
December	1.10	1.55	+.45	−.29
January	1.24	1.19	−.05	−.34
February	1.01	.76	−.25	−.59
March	.84	.93	+.09	−.50
April	.99	1.56	+.57	+.07
May	1.14	1.16	+.02	+.09
June	.90	.05	−.85	−.76
July	.43	.06	−.37	−1.13
August	.26	.07	−.19	−1.32
1917–18				
September	.70	.72	+.02	+.02
October	.93	0	−.93	−.91
November	1.17	1.40	+.23	−.68
December	1.10	.07	−1.03	−1.71
January	1.24	1.22	−.02	−1.73
February	1.01	.56	−.45	−2.18
March	.84	.58	−.26	−2.44
April	.99	.86	−.13	−2.57
May	1.14	.93	−.21	−2.78
June	.90	.58	−.32	−3.10
July	.43	.43	0	−3.10
August	.26	.27	+.01	−3.09
1918–19				
September	.70	.81	+.11	+.11
October	.93	1.60	+.67	+.78
November	1.17	.49	−.68	+.10
December	1.10	.48	−.62	−.52
January	1.24	.51	−.73	−1.25
February	1.01	1.23	+.22	−1.03
March	.84	1.24	+.40	−.63
April	.99	.98	−.01	−.64
May	1.14	.14	−1.00	−1.64
June	.90	0	−.90	−2.54
July	.43	.24	−.19	−2.73
August	.26	.01	−.25	−2.98
1919–20				
September	.70	1.49	+.79	+.79
October	.93	.72	−.21	+.58
November	1.17	1.07	−.10	+.48
December	1.10	.90	−.20	+.28
January	1.24	.29	−.95	−.67
February	1.01	.85	−.16	−.83
March	.84	.59	−.25	−1.08
April	.99	1.72	+.73	−.35
May	1.14	.53	−.61	−.96
June	.90	.26	−.64	−1.60
July	.43	.09	−.34	−1.94
August	.26	.19	−.07	−2.01
1920–21				
September	.70	.49	−.21	−.21
October	.93	2.71	+1.78	+1.57
November	1.17	1.31	+.14	+1.71
December	1.10	.90	−.20	+1.51
January	1.24	1.13	−.11	+1.40
February	1.01	1.09	+.08	+1.48
March	.84	.45	−.39	+1.09
April	.99	1.44	+.45	+1.54
May	1.14	2.78	+1.64	+3.18
June	.90	.61	−.29	+2.89
July	0.43	0.08	−0.35	+2.54
August	.26	.89	+.63	+3.17
1921–22				
September	.70	.06	−.64	−.64
October	.93	.10	−.83	−1.47
November	1.17	1.33	+.16	−1.31
December	1.10	1.33	+.23	−1.08
January	1.24	1.43	+.19	−.89
February	1.01	.88	−.13	−1.02
March	.84	.91	+.07	−.95
April	.99	1.20	+.21	−.74
May	1.14	1.35	+.21	−.53
June	.90	.84	−.06	−.59
July	.43	.42	−.01	−.60
August	.26	.88	+.62	+.02
1922–23				
September	.70	.01	−.69	−.69
October	.93	.17	−.76	−1.45
November	1.17	.67	−.50	−1.95
December	1.10	.65	−.45	−2.40
January	1.24	.64	−.60	−3.00
February	1.01	.17	−.84	−3.84
March	.84	.32	−.52	−4.36
April	.99	2.41	+1.42	−2.94
May	1.14	1.60	+.46	−2.48
June	.90	2.36	+1.46	−1.02
July	.43	.88	+.45	−.57
August	.26	.27	+.01	−.56
1923–24				
September	.70	1.34	+.64	+.64
October	.93	1.81	+.88	+1.52
November	1.17	.59	−.58	+.94
December	1.10	.84	−.26	+.68
January	1.24	.20	−1.04	−.36
February	1.01	1.12	+.11	−.25
March	.84	.12	−.72	−.97
April	.99	.04	−.95	−1.92
May	1.14	.22	−.92	−2.84
June	.90	.15	−.75	−3.59
July	.43	.10	−.33	−3.92
August	.26	.26	0	−3.92
1924–25				
September	.70	.12	−.58	−.58
October	.93	1.66	+.73	+.15
November	1.17	.51	−.66	−.51
December	1.10	2.03	+.93	+.42
January	1.24	1.42	+.18	+.60
February	1.01	1.13	+.12	+.72
March	.84	1.25	+.41	+1.13
April	.99	1.12	+.13	+1.26
May	1.14	.83	−.31	+.95
June	.90	1.15	+.25	+1.20
July	.43	1.50	+1.07	+2.27
August	.26	.70	+.44	+2.71
1925–26				
September	.70	.92	+.22	+.22
October	.93	.37	−.56	−.34
November	1.17	.91	−.26	−.60
December	1.10	.82	−.28	−.88
January	1.24	.33	−.91	−1.79
February	1.01	1.00	−.01	−1.80
March	.84	.38	−.46	−2.26
April	.99	1.19	+.20	−2.06
May	1.14	.31	−.83	−2.89
June	.90	(1)	−.90	−3.79
July	.43	.58	+.15	−3.64
August	.26	.10	−.16	−3.80

[1] Trace.

TABLE 36.—*Precipitation at Twin Falls, Idaho, seasons of 1905–6 to 1927–28, inclusive*—Continued

Season and month	Normal	Actual	Deviation from normal	Accumulated deviation from normal	Season and month	Normal	Actual	Deviation from normal	Accumulated deviation from normal
1926–27	*In.*	*In.*	*In.*	*In.*	1927–28	*In.*	*In.*	*In.*	*In.*
September	0.70	0.03	−0.67	−0.67	September	0.70	0.69	−0.01	−0.01
October	.93	.35	−.58	−1.25	October	.93	1.03	+.10	+.09
November	1.17	1.72	+.55	−.70	November	1.17	1.70	+.53	+.62
December	1.10	.77	−.33	−1.03	December	1.10	.33	−.77	−.15
January	1.24	.68	−.56	−1.59	January	1.24	.83	−.41	−.56
February	1.01	1.55	+.54	−1.05	February	1.01	.33	−.68	−1.24
March	.84	.41	−.43	−1.48	March	.84	2.18	+1.34	+.10
April	.99	1.38	+.39	−1.09	April	.99	.40	−.59	−.49
May	1.14	2.24	+1.10	+.01	May	1.14	.16	−.98	−1.47
June	.90	.04	−.86	−.85	June	.90	1.06	+.16	−1.31
July	.43	.04	−.39	−1.24	July	.43	.11	−.32	−1.63
August	.26	.15	−.11	−1.35	August	.26	(1)	−.26	−1.89

[1] Trace.

The data in Table 36 suggest that the sign of the accumulated deviation of precipitation at the end of February is maintained for the rest of the precipitation year. There are few exceptions to this generalization. The greater the accumulated deviation at the end of any one month, the greater is the possibility of a monthly deviation of the opposite sign in the immediately succeeding month.

THE DISTRIBUTION OF EUTETTIX TENELLUS AND ITS PROBABLE LIMITS OF ECONOMIC SPREAD[6]

REQUIREMENTS FOR THE USE OF THE CLIMOGRAPH

The climograph of John Ball (*2*) has been extensively used in recent years as a means of comparing climates with respect to precipitation and temperatures by Huntington (*20*), Cook (*11*, *13*), and Seamans (*25*). These writers have plotted the mean monthly temperature and monthly precipitation, the graph forming a closed polygon.

The fundamental requirement for the proper use of the climograph in entomological work is a study of the insect concerned under specific climatic conditions, preferably those which typify the optimum for the insect as far as that can be determined. If the study can be extended to include conditions which vary from optimum to very much less favorable, the significance of slight differences can be more properly evaluated.

The present use of the climograph as a means of determining the probable limits of the insect's range is based on such a study. The Snake River Valley, from Sugar City (which is close to the west entrance of Yellowstone National Park) south to Pocatello, then west to Glenns Ferry, offers a range of conditions within which the insect finds an environment gradually approaching optimum and reaching its peak between Twin Falls and Glenns Ferry.

The usual method of using mean temperatures is not applicable to this case, since the significant points are found in extremes and the

[6] This study does not include California. Climatic conditions are so varied there that limiting factors are probably of an entirely different nature from those encountered east and north of that State. Without personal acquaintance with the environment of the insect there, the writer considered it inadvisable to include California in this study. Detailed data on the insect in California may be found in the writings of H. H. P. Severin (*26*, *27*, *28*).

average rarely happens. Since the data must, for purely physical reasons, be averaged to some extent, mean maxima and mean minima have been taken, so that for each locality there are two climographs, precipitation of course being the same in each case.[7]

THE SNAKE RIVER VALLEY FROM SUGAR CITY TO GLENNS FERRY, IDAHO

The mean maxima gradually decrease in passing up the Snake River Valley from Glenns Ferry to Sugar City. Rupert and Twin Falls show climographs almost exactly similar in all respects. (Fig. 24.) The influence of proximity of mountains is seen at Pocatello, this influence becoming more pronounced as Sugar City is reached.

The mean minima, especially in the winter months, decrease progressively as the location changes eastward and northward. Precipitation, especially in the months of May, June, and July, increases in the same direction.

Since curly-top outbreaks gradually diminish as one goes east and north, the significance of differences in these climographs can be determined.

MEAN MINIMA

Outbreaks from Rupert to Twin Falls are (as reference to the section on forecasting will show) conditioned largely by deviations from the mean minima. The climate of this portion of the area represents a finely balanced condition which requires only a deviation in either direction to produce either an outbreak or freedom from one. Comparing the mean minima of these two places with those of Idaho Falls, where serious outbreaks are rare, and Sugar City, where they are still more rare, it is seen that slight differences in mean minima are of great importance in indicating the much greater deviations from the normal which are necessary before the conditions in the last two places are brought within the danger zone. These normal mean minima are averages of temperatures actually occurring over periods of many years. The detailed charts (figs. 13 to 22) referred to in the section on forecasting indicate for a period of 10 years just what extremes the differences in normal mean minima between Twin Falls and Idaho Falls involve.

MEAN MAXIMA

In the Twin Falls district the winter and spring maxima are of great importance in governing the preoviposition period of the overwintering females, the speed of development of the first brood, and the maturity of the short-lived host plants. The influence of this factor varies from a maximum at Glenns Ferry to a minimum at Sugar City.

PRECIPITATION

As in the case of minimum temperatures, the Twin Falls area is finely balanced with respect to precipitation and its effect on outbreaks. The significant points involved here are incidence of rainfall as well as its quantity. Rainfall in the fall of the year is undoubtedly of great importance in conditioning the capacity of the insect to survive the winter, either with respect to succeeding low temperatures

[7] The climatological data used for these climographs are taken from the published records of the Weather Bureau.

or with respect to host plants. (See section on host-plant relationships.) After the winter has operated with respect to success of hibernation, rainfall in the spring and early summer is probably the

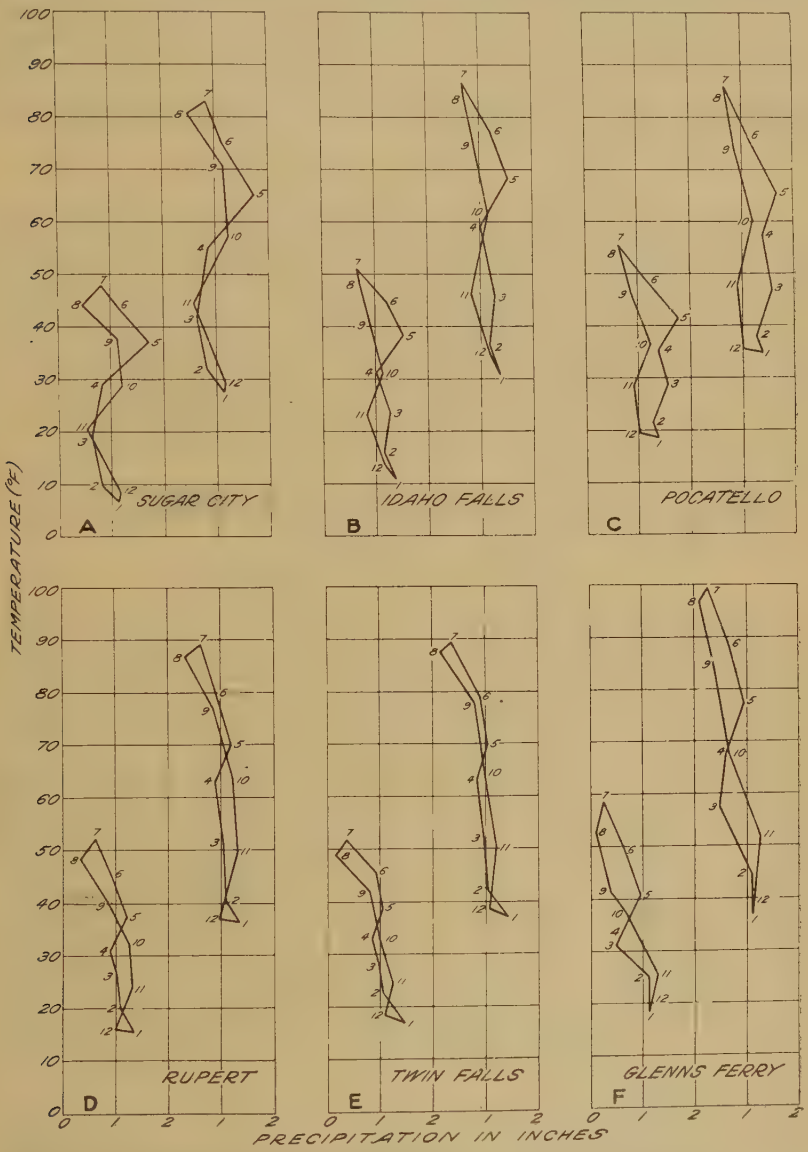


FIGURE 24.—Climographs of localities in the Snake River Valley, in Idaho, from Sugar City to Glenns Ferry

most important factor involved. An extremely dry spring with its correlated high temperature is invariably associated in this area with an outbreak if conditions have been favorable for hibernation the previous winter.

As in the case of temperatures, the rainfall varies with the locality, although there is not the steady, uninterrupted change in one direction. The heavier rainfall of Pocatello undoubtedly contributes to offset the similarity of its mean minima to those of Twin Falls. The rainfall of Sugar City has a distribution slightly different from that of Idaho Falls, but from Idaho Falls to Sugar City in 1926, which was one of the driest years on record, aphid injury on beets was very pronounced. This is an indication of lower evaporation rates and higher humidities, which the lower temperatures would lead one to expect.

SUMMARY OF CLIMATIC CONDITIONS

To summarize, the climatic conditions of the area of which Twin Falls is the center are such as to provide a finely balanced condition with respect to outbreaks of *E. tenellus*. The mean minima for the winter months at Twin Falls represent therefore an index base line with which the mean minima in other places can be compared, lower mean minima indicating the more frequent occurrence of limiting extremes, and higher mean minima indicating more successful hibernation. High mean maxima in the spring months condition the development of the first brood and the suitability of the short-lived annual host plants.

Precipitation is important with respect to incidence and quantity. The normal quantity in the Twin Falls district can also be taken as an index base line for comparative purposes.

LOCALITIES IN OREGON AND WASHINGTON

In Oregon and Washington we have two very different sets of climatic conditions. The area west of the Cascades in Oregon, typified by Grants Pass and the Bellingham district, represents the high-rainfall belt of the Pacific Northwest on the one hand and, on the other, six locations from these two States represent climatic conditions east of the Cascades. (Figs. 25 and 26.)

Observations in the Willamette Valley in Oregon indicate clearly that this coastal area is not one where the insect can successfully hibernate. Through the courtesy of M. B. McKay, the writer was taken in the early spring of 1927 to places where beets had suffered severely from curly top in the summer of 1926 and where the insect had been plentiful. No indications that the insect had survived were found. The native vegetation was rank and relative humidities were high. The area was visited again in the middle of June, 1927, again with negative results. These high rainfall areas of the Pacific coast suggest therefore another limiting factor on the spread of the insect. The writer has conducted experiments on the effect of high humidities at temperatures between 50° and 60° F. and has found that these are fatal if long maintained.

The dry midsummers, however, are of very great importance if the insect migrates into these areas at that time, because temperatures are normally favorable at that season and precipitation is low. If the migration occurs in an abnormally dry season, as in 1926, great damage ensues.

This applies with more force to the Willamette Valley than to the Bellingham (Wash.) area where the summer maxima, even in the drier part of the season, are much lower, and precipitation is slightly higher than in the Willamette Valley.

East of the Cascades the climographs closely approximate that of Twin Falls. A beet-sugar factory was moved out of Sunnyside, Wash., in 1925 on account of outbreaks of *E. tenellus*, and two other factories in the Yakima Valley shared the same fate. Wilbur is taken as representing the dry-land section of eastern Washington. In this case the mean minima are such as to offer occasional freedom from

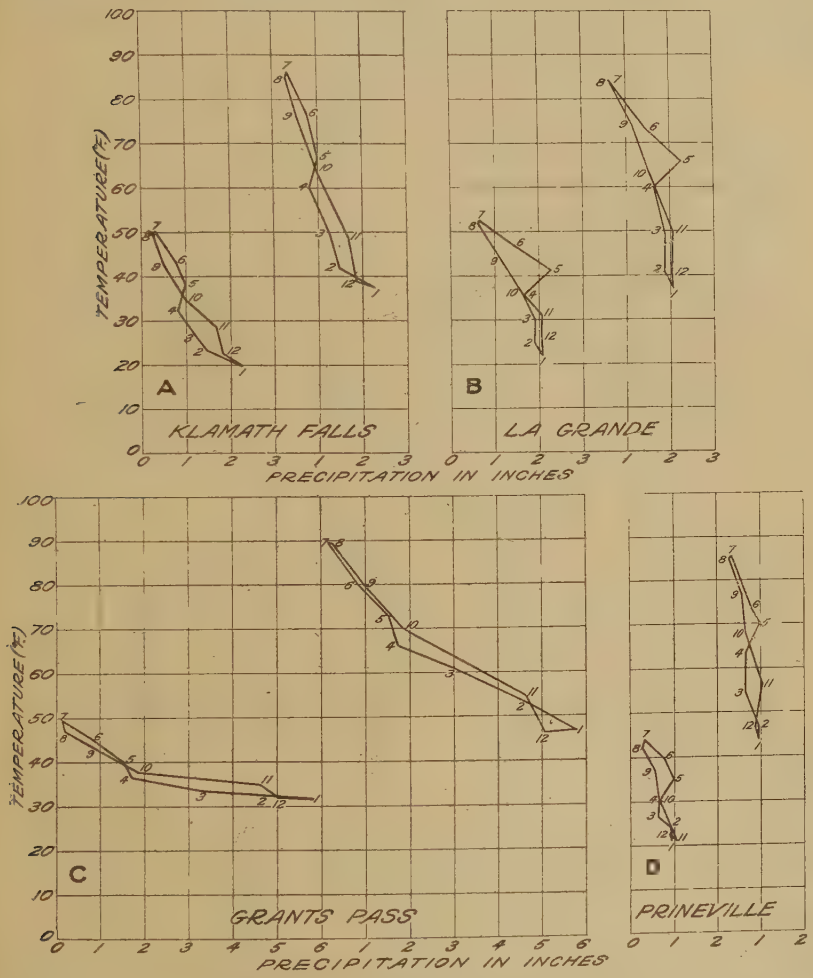


FIGURE 25.—Climographs of localities in Oregon

outbreaks, but the precipitation is too low for safety with respect to that factor.

Prineville, Oreg., was visited by the writer in 1925, and serious disease was noted on mangels and test plots of sugar beets. Test plots the previous year had all failed. *E. tenellus* was found widely scattered over the district and in considerable numbers. La Grande, Oreg., has a climograph indicating that limiting minimum temperatures are very rare. Spring rainfall is higher, but a series of dry seasons eliminated the sugar-beet industry in that region some years ago.

LOCALITIES IN MONTANA

The State of Montana, lying as it does in such close proximity to the great breeding grounds in Idaho, offers an excellent opportunity for the study of limiting factors. The presence of the insect east of

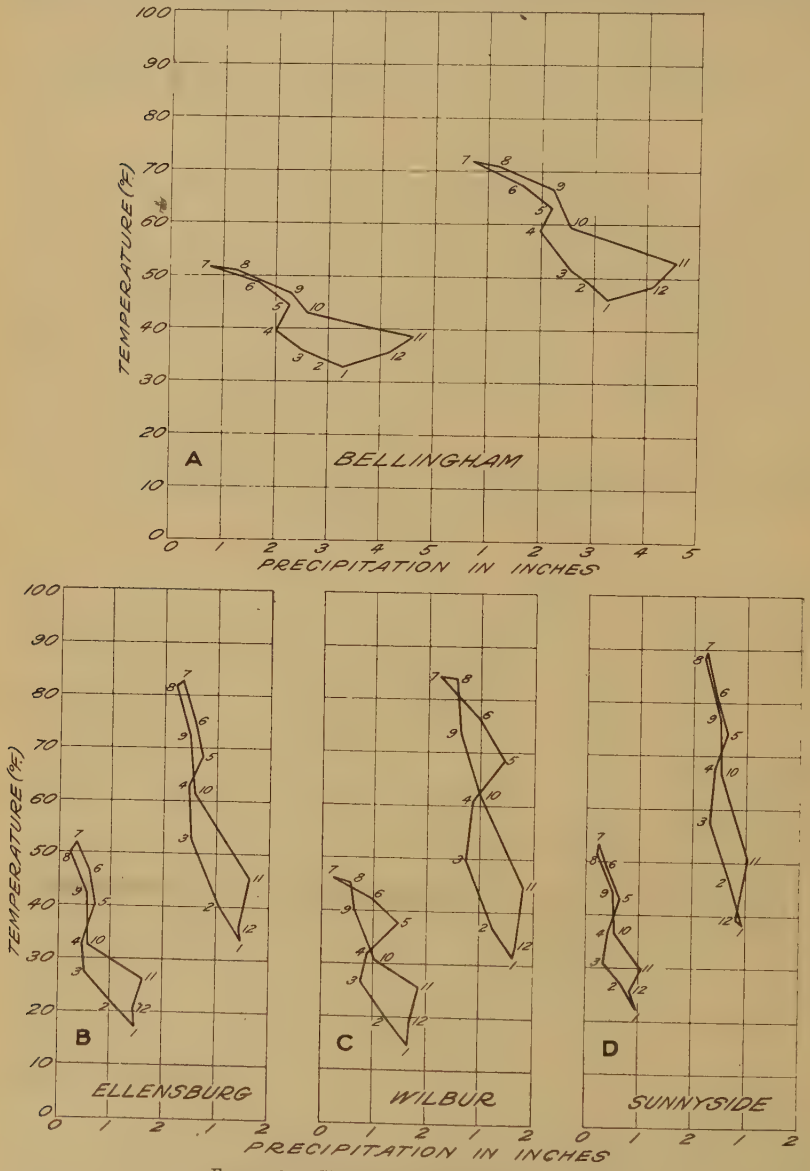


FIGURE 26.—Climographs of localities in Washington

the Rockies has been reported (7), and it is extremely probable that migrations into that area have repeatedly occurred during the years of great dispersions. The climographs of Havre, Miles City, Glasgow, and the agricultural college at Bozeman, with their low mean

minima and high summer rainfall, provide, the writer believes, an adequate explanation of the failure of the insect to become established there. (Fig. 27.)

The Bitterroot (Missoula) and Flathead (Kalispell) districts are extremely interesting as border-line zones. There is easy connection between these districts and the breeding grounds of Idaho and Washington, and the probability is that some *E. tenellus* find their way into them every year. Low mean minima, together with the high

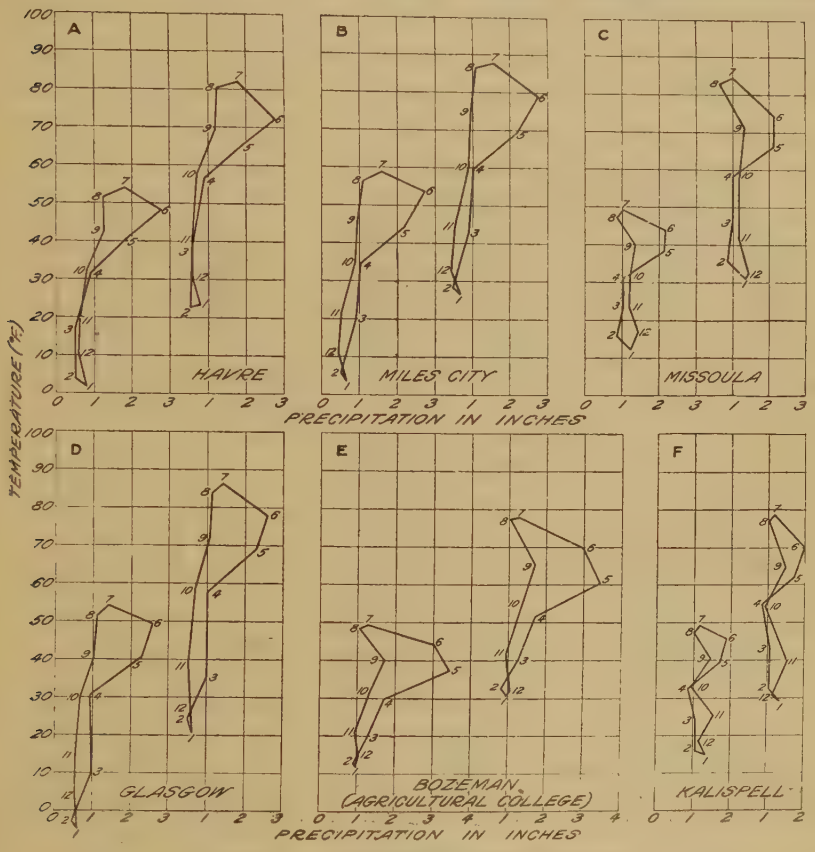


FIGURE 27.—Climographs of localities in Montana

summer precipitation normal to these areas, indicate that freedom from serious outbreaks can be reasonably expected, and it was on the basis of these data, coupled with personal observations in the territory, that a report to that effect was made to a sugar company investigating the area prior to establishing a factory there.

The finding of a single specimen of *E. tenellus* in a small beet patch in the Bitterroot Valley in September, 1927, as well as six or seven cases of disease in the same patch, indicates that such occurrences may be expected. The amount of this infestation will be determined by conditions in the dispersal area from which the insects come, as well as temperatures and precipitation in the valleys after the influx. An abnormally dry and hot summer permits an abnormal development of both insect and disease. Visits to the Bitterroot and Flat-

head districts in May and September, 1927, where locations of leafhopper populations in 1926 (7) were given special attention, indicate strongly that these districts are not favorable for the overwintering of the insect.

These districts are also under the influence of the foehn winds. The extremes and sudden changes of temperature associated with these winds are hidden in the averaged temperatures. These condi-

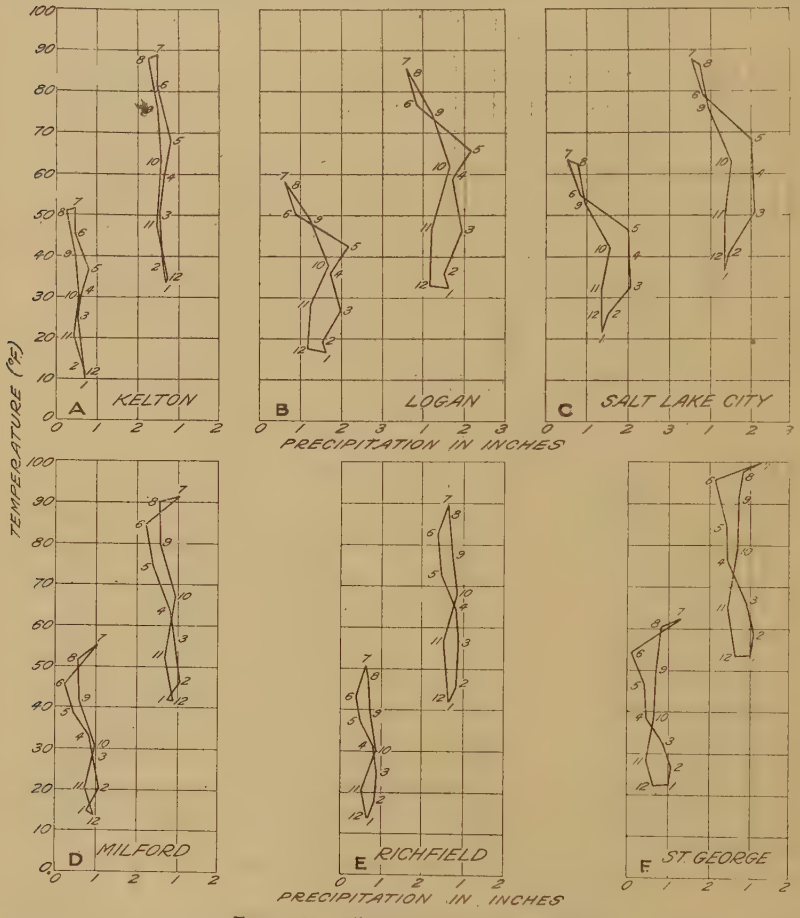


FIGURE 28.—Climographs of localities in Utah

tions probably represent another limiting factor, that of fluctuating winter temperatures. Reference to the detailed charts presented in the section relating to forecasting will indicate that recurring low temperatures, with periods of higher temperatures in between, are inimical to successful hibernation.

LOCALITIES IN UTAH

The climographs shown in Figure 28 illustrate the wide variety of conditions met with in Utah.

St. George, in the southern end of the State, represents the most extreme conditions encountered. Precipitation is low, but the mean

maxima indicate the early hot spring weather. The probability of a very early spring brood developing is very great, and this district is being studied at the present time as a possible dispersal area for the Sevier Valley.

Richfield is taken as representative of the Sevier Valley climate. The mean minima indicate the more frequent occurrence of limiting extremes of low temperature than is the case in Twin Falls. Observations made by E. W. Davis in that district in the winter of 1926–27 suggest that overwintering in the valley is rare. The low precipitation during the spring and summer months constitutes a real danger, since conditions are thus made very favorable to the insect's rapid development. In years when the precipitation is below normal, this is even more pronounced.

Milford is typical of a large area in southeastern Utah. The mean minima indicate that extremes of limiting low temperature are of fairly frequent occurrence. The precipitation is low and this factor probably operates to produce an unfavorable host-plant condition. This district is also under observation as a possible dispersal area.

At Salt Lake City the normal precipitation is a factor in favor of the district. The winter minima are dangerous. In the vicinity of Salt Lake City the areas of wild host plants are small and this no doubt helps to reduce the amount of damage in that vicinity. However, considerable damage is done every year, presumably as a result of migration into the area.

Logan, as representative of Cache Valley conditions, offers two limiting factors—one, the mean minima, and the other, the higher precipitation. Cache Valley, in general, suffers less damage than any other important beet-growing district in Utah. Even in 1926, a most disastrous year generally over the beet-growing areas in Utah and Idaho, a trip taken over the valley failed to indicate that curly top was the principal factor in the beet situation at that time. The cultivated sections of the Cache Valley are not to any degree, if at all, overwintering areas for the insect. The vegetation along the roadsides is rank and densely matted—a condition usually associated with freedom from *E. tenellus*.

Kelton, in the northwestern corner, has a climograph suggesting the very frequent occurrence of extremes of low temperatures. An abnormally mild winter would no doubt be followed by high populations of *E. tenellus*, with a very likely prospect of the host plants soon becoming unfavorable.

Considering the problem in Utah as a whole, it seems likely that none of the beet-growing districts are located in permanent breeding grounds (Delta having been recently abandoned) and that before forecasting can be attempted there the dispersal areas for the whole State must be known and basic data accumulated as to the weather and its relations to the insect.

LOCALITIES IN COLORADO

Boulder, Colo., lies in a district where beet growing has been most successful and where no damage from curly top has ever been reported The host-plant areas in this territory are very limited, but the principal factor operating appears to be summer precipitation. (Fig. 29.) The district is also in the foehn wind belt, but the significance of this

factor is not indicated by mean temperatures. Areas of high summer rainfall appear generally to be free from outbreaks of *E. tenellus*.

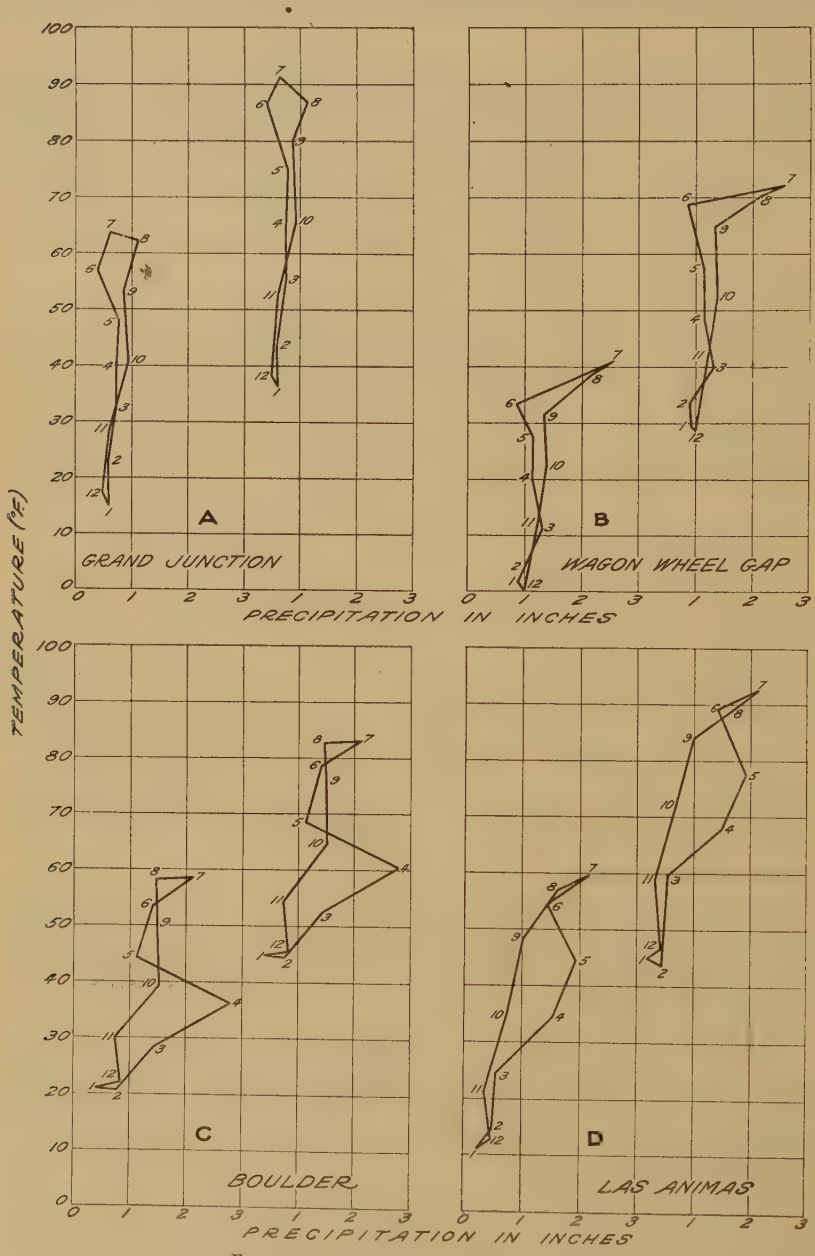


FIGURE 29.—Climographs of localities in Colorado

Las Animas, in the Arkansas Valley of Colorado, is another case in point, although low temperatures are an additional factor there. The records for curly top in this district indicate clearly that the dispersal

area for the leaf hoppers found there is not close at hand but more probably lies to the southwest. The data on insect collections there are discussed at the end of this section.

Wagon Wheel Gap, high on the plateau of the San Luis Valley, is obviously influenced by its high altitude and the limiting factor in

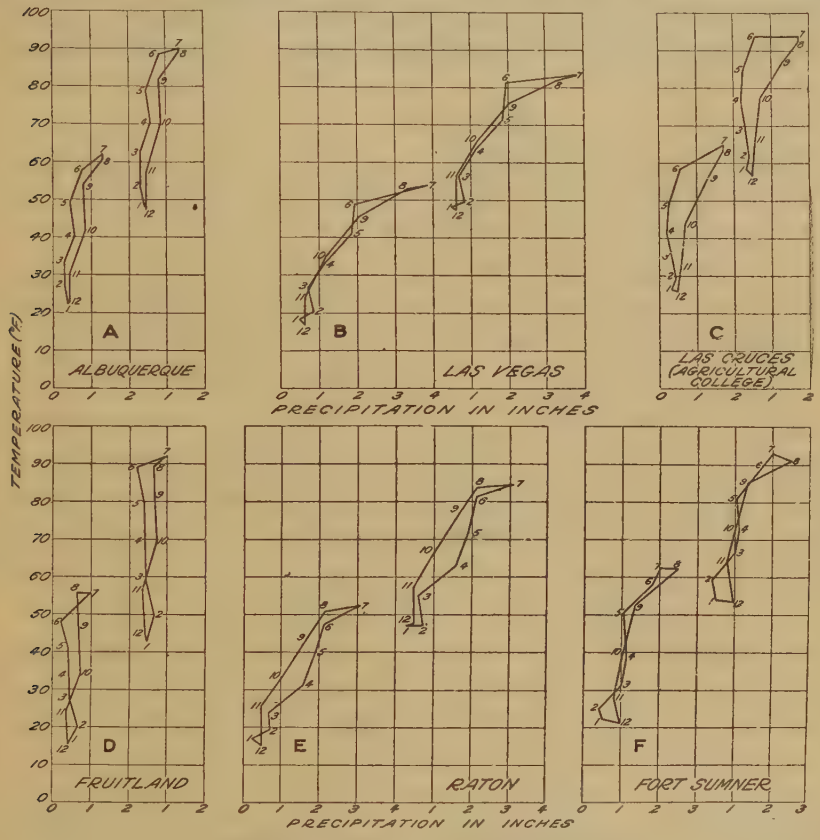


FIGURE 30.—Climographs of localities in New Mexico

beet growing in the district would not be *E. tenellus* but the shortness of the season.

Grand Junction, Colo., has a climograph very similar to that of Twin Falls. The records of disease are not complete but are sufficient to indicate that serious outbreaks occur in that section.

LOCALITIES IN NEW MEXICO

Albuquerque, with a climograph closely approximating that of Twin Falls, is in a district seriously affected by curly top. Fruitland's climograph indicates that the same conditions are met with in the northeastern corner of the State. (Fig. 30.)

Curly top has been for years a serious bar to beet growing at Las Cruces (Agricultural College) (*23*). Fort Sumner represents a condition where the incidence of the rainfall eliminates curly top as a limiting factor.

Raton, in the northeastern part of the State, has the most satisfactory climograph from the standpoint of freedom from outbreaks of *E. tenellus*. Mean minima are favorable and the precipitation is normally high. Las Vegas has very similar conditions. The comparison of the curly-top records for 1926 for the Las Cruces and Albuquerque districts with those for Las Vegas indicates that the latter place receives its leaf hoppers from the former. Damage was much less at Las Vegas and more closely approximated the conditions in the

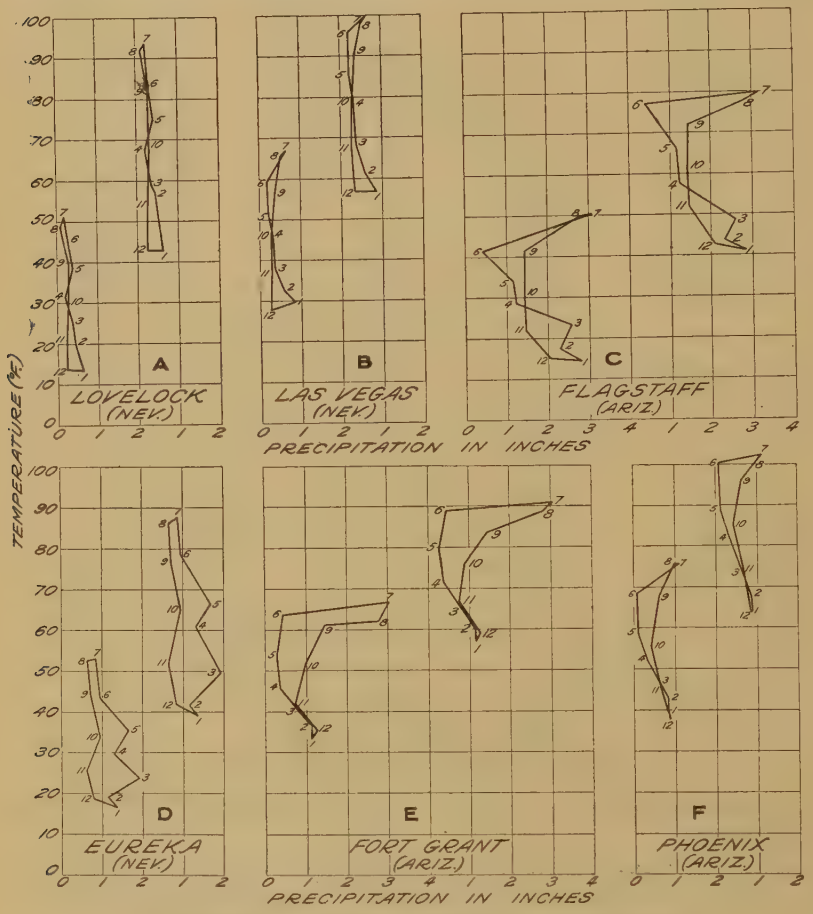


FIGURE 31.—Climographs of localities in Nevada and Arizona

Arkansas Valley. This illustrates the point that a locality normally safe may become infested, owing to an abnormal season wherein the limiting factors may be temporarily eliminated.

LOCALITIES IN ARIZONA AND NEVADA

Phoenix, Ariz., and Las Vegas, Nev., are both places where the insect may be expected to be normally present. (Fig. 31.) The host-plant factor will undoubtedly enter in, since the temperatures will preclude any but typical desert plants on which large populations have never been found.

Lovelock, Nev., has suitable low mean minima, but precipitation is also low and therefore unfavorable. Eureka, Nev., would probably escape serious damage in a normal year, but abnormally open winters and reduced spring precipitation would be disastrous. This is also true of Flagstaff, Ariz., but precipitation conditions are more finely balanced and would therefore become unfavorable more easily and oftener. Fort Grant, Ariz., would probably approximate Phoenix, although the insect has not been studied in a district with the fall precipitation of Fort Grant.

LOCALITIES IN WYOMING

Low mean minima are the principal limiting factors in preventing the insect's permanent establishment in Wyoming. (Fig. 32.) The

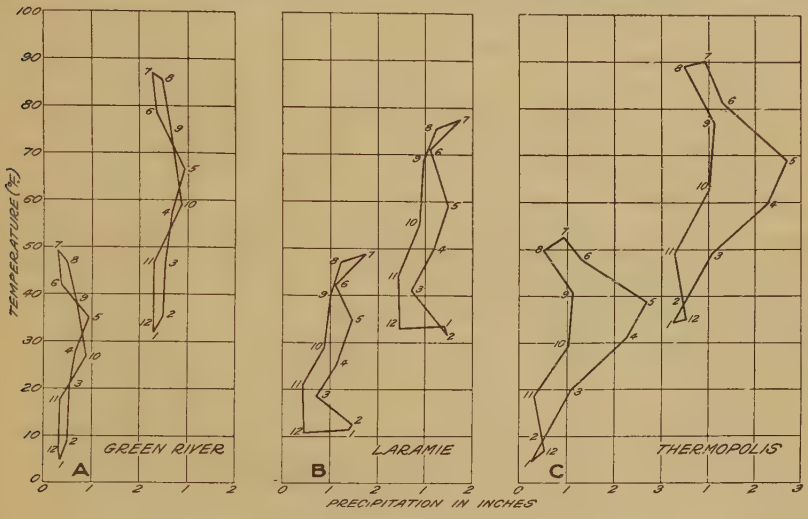


FIGURE 32.—Climographs of localities in Wyoming

close proximity of this State to the breeding grounds in Idaho and Utah indicates that migration must have repeatedly carried *E. tenellus* into this State. Asa C. Maxson informs the writer that occasional disease is found at Wheatland and that in 1926 the disease in the beet fields amounted to 4 per cent, and in 1927, approximately 1 per cent.

LOCALITIES IN TEXAS

Amarillo, Midland, and Fort McKavett are locations where the precipitation is such as to be considered a limiting factor, even though mean minimum temperatures are high. (Fig. 33.) The disease has been recorded at Amarillo (*1*), but whether serious visitations could be expected is a matter to be determined.

These three places represent the only ones where the study has revealed a climate approximating that of the beet-growing districts.

The climograph of Galveston represents the high temperatures and precipitation of the Gulf coast. The latter factor is undoubtedly limiting.

LOCALITIES IN OTHER STATES

The climographs of typical localities in North Dakota, South Dakota, Nebraska, and Kansas all furnish evidence of the limiting factors of either low mean minima or high precipitation, or both, and, unless the insect is in process of adaptation, there appears to be little danger

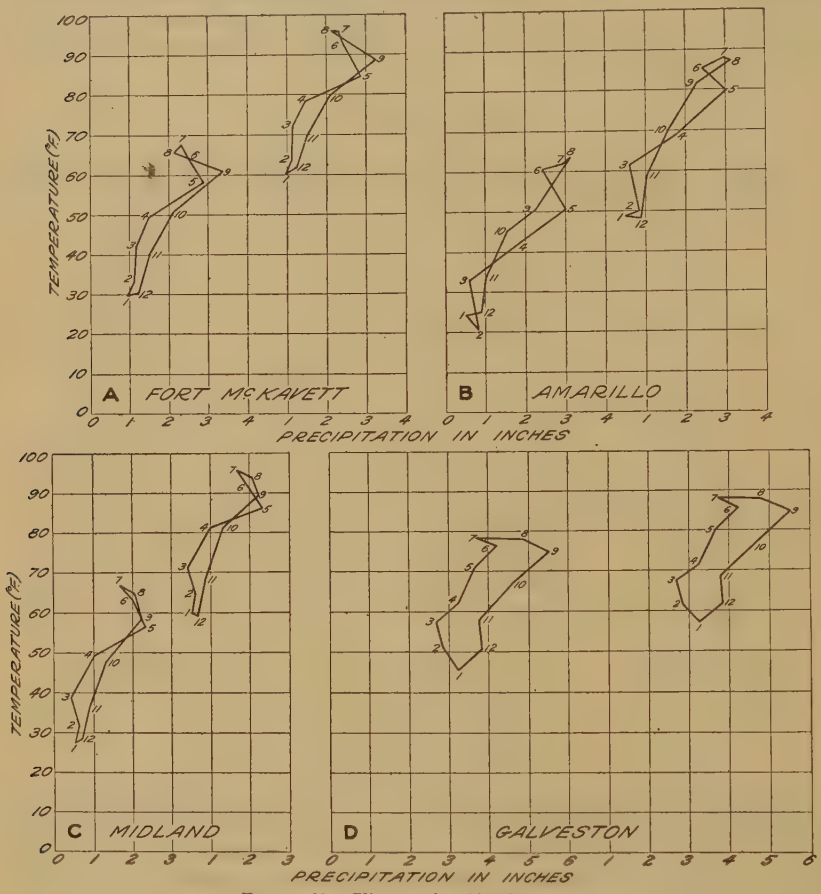


FIGURE 33.—Climographs of localities in Texas

of economic populations of *E. tenellus* developing in these localities. (Fig. 34.)

SPECIFIC PREDOMINANCE AS AN INDEX OF THE ENVIRONMENTAL COMPLEX

Two localities, both border line as far as *E. tenellus* is concerned, offer an opportunity to examine the insects collected on host plants normally very favorable to *E. tenellus*, with a view to ascertaining the predominant host species and, secondly, the predominant leaf hopper. The writer made a series of eight collections, representing a cross section through the Arkansas Valley of Colorado. Only those locations were chosen which had the general characteristics of large *E. tenellus* population centers as far as host plants and type of growth were concerned. These data are listed in Table 37. Similar data from the Bitterroot Valley, Mont., are presented in Table 38.

TABLE 37.—*Insects collected on host plants of Eutettix tenellus in the Arkansas Valley, Colo., 1927*

Date	Host	E. tenellus				Total other species	Remarks
		Males	Females	Nymphs	Total		
Sept. 22	Sparse growth of Russian thistle.	1	1	0	2	500	Predominant insect Agallia sp., easily predominant over all other insects.
23	Amaranthus	1	1	1	3	60	Agallia sp. predominant, equal to all others combined.
23	Beets	2	5	0	7	441	Predominant insect is a leaf hopper, Eugnathodus abdominalis Van D.
23	Russian thistle (roadside).	0	0	0	0	228	Agallia sp. predominant insect, predominating over all others combined.
22	do	1	2	1	3	172	Do.
23	Sarcobatus	0	0	0	0	268	Predominant insect, a coleopteron; commonest leaf hopper, Agallia sp.
22	Russian thistle (roadside).	1	3	1	5	504	Agallia sp. predominant over all others.
22	Amaranthus	0	1	0	1	700	Agallia sp. predominant, equal to all others.

TABLE 38.—*Insects collected on host plants of Eutettix tenellus in the Bitterroot Valley, Mont., 1927*

Date	Place	Host	Remarks
Sept. 7	St. Augustina	Russian thistle and Atriplex rosea.	Predominant insect, Agallia sp. Predominant group, leaf hoppers. No tenellus.
8	Charlo	Beets	Predominant insect and predominant over all others combined, flea beetle. 7 species of leaf hoppers approximately equal in numbers, with Agallia sp. slightly predominant. No E. tenellus.
7	Missoula	Russian thistle and A. rosea.	Predominant insect, Lygus elisus. No E. tenellus; 4 species of leaf hoppers approximately equal.
9	Just south of Bitterroot River.	Russian thistle	Agallia sp. predominant leaf hopper and equal to all other leaf hoppers. Predominant group Diptera.
9	Stevensville	do	Predominant group Diptera. Predominant insect a leaf hopper, Deltocephalus striatus. No E. tenellus.
8	Pablo	Russian thistle in stubble.	Diptera predominant group. No leaf hoppers.
8	Charlo	Russian thistle and A. rosea.	Predominant groups, leaf hoppers and Diptera. No predominant species. No E. tenellus.
9	Lolo	Sparse Russian thistle.	Diptera and Hemiptera predominant. Leaf hoppers Agallia sanguinolenta and Euscelis exitiosus. No Eutettix tenellus.
7	De Smets	Amaranthus	Predominant group Coleoptera. Leaf hoppers A. sanguinolenta and E. exitiosus. No Eutettix tenellus.
9	Missoula	Russian thistle	Predominant insect, flea beetle. No group predominant. No tenellus. One Agallia species and one other leaf hopper.

From Table 37 it will be observed that in the Arkansas Valley the predominant species on the wild annual hosts of *E. tenellus* is *Agallia* sp.; on beets another leaf hopper, *Eugnathodus abdominalis* Van D. On Sarcobatus the predominant leaf hopper was *Agallia* sp. It is also notable that in the case of all the annual hosts, *Agallia* sp. was not only the predominant species, but in each case its numbers either equaled or exceeded all other insects combined.

In the area studied in Idaho (Table 39) the situation is almost exactly reversed, Agallia populations bearing somewhat the same relationships to those of *E. tenellus* as *tenellus* does to Agallia in the Arkansas Valley. In Idaho *Agallia* sp. is found commonly in rather damp situations and is especially noticeable in the early spring. In

1927 it was noticeably abundant in the beet fields which generally provided a densely shaded and humid environment.

The climographs of the Arkansas Valley differ from those of the Idaho area principally in the amount of precipitation and its seasonal incidence, but the reversal of predominance is significant and

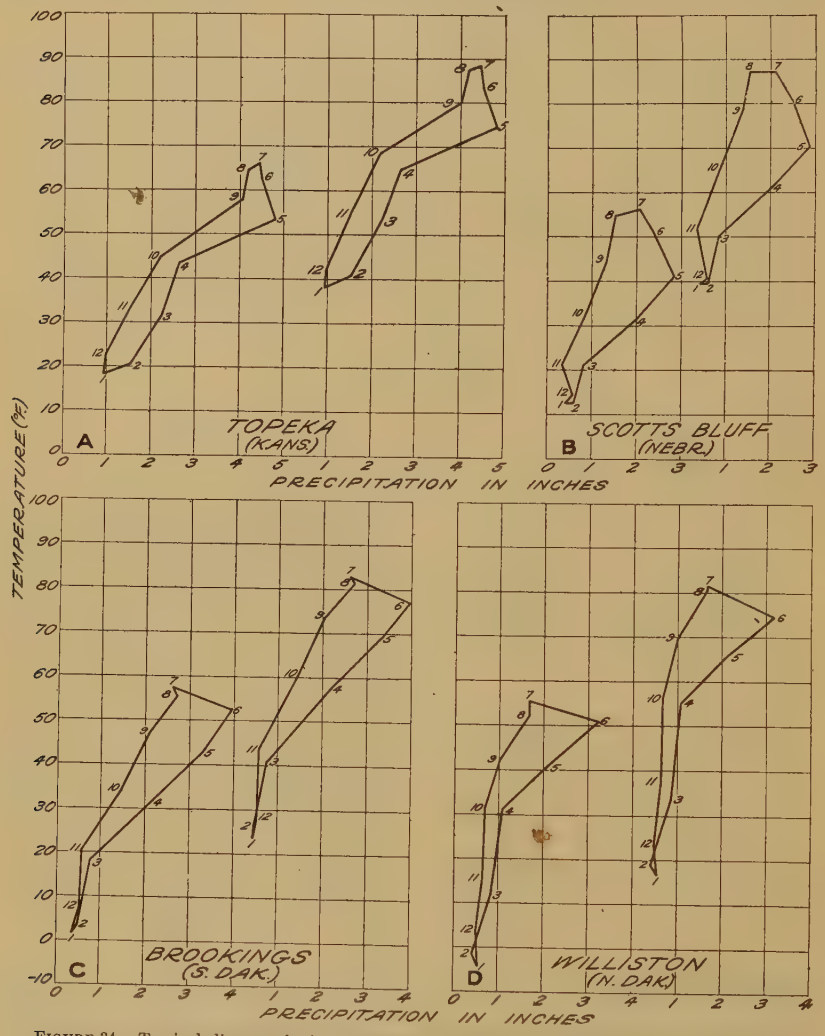


FIGURE 34.—Typical climographs from Kansas, Nebraska, South Dakota, and North Dakota

suggests an indicator for use by explorers seeking specific forms which may be limited to certain environmental complexes, and as a method of determining subareas differing from the main area for which weather and other environmental data are alone available this concept may properly find use. It will become more available as the detailed environmental optima of other species are worked out so that the temporary predominance of certain species due to deviation from the normal climatic conditions of a particular area may be properly evaluated (*12*).

The climate of this valley differs from that of the Idaho area in having more rain in summer and cooler temperatures generally throughout the year. The winter is generally of a different type, the daily temperatures fluctuating within wide limits.

On the trip during which these collections were made, 1 specimen of *E. tenellus* was captured in a small patch of beets and some six or seven cases of curly top averaging 1 case to 150 feet of row were observed.

Reference to Table 37 will show that predominance is divided. However, *Agallia sanguinolenta* still occupies an important position, with *Deltocephalus striatus* and *Euscelis exitiosus* sharing it in some instances.

A series of collections made in this area in June, 1927, by J. R. Parker, of the Montana Agricultural Experiment Station, when better conditions for collecting prevailed, indicate that six species comprised approximately 90 per cent of all the leaf hoppers collected. These were *A. sanguinolenta*, *Deltocephalus striatus* L., *D. collinus* Boh., *D. misellus* Ball, *Cicadula 6-notata* (Fall.), and *E. exitiosus*. Of these *A. sanguinolenta*, *D. striatus*, and *D. misella* were approximately equal in numbers, with *D. striatus* slightly predominating.

The data presented in Table 39 indicate clearly the relation between *E. tenellus* and other insect species in the Twin Falls district, where the conditions are favorable to *E. tenellus*.

TABLE 39.—*Insects collected on host plants of Eutettix tenellus in the Twin Falls district, illustrating the predominance of E. tenellus in 1927*

Date	Host	E. tenellus				Other species
		Males	Females	Nymphs	Total	
Sept. 18	Salsola pestifer	10	17	16	43	30
	do	25	58	31	114	89
	do	108	153	120	381	61
	do	11	17	12	40	87
	do	50	150	104	304	57
	do	99	215	104	418	22
	do	47	118	29	194	37
	S. pestifer and Atriplex rosea	36	53	16	105	92
	S. pestifer	59	140	90	289	35
	do	10	37	3	50	18
	do	35	70	39	149	31
	do	58	197	51	306	21
	do	60	116	71	247	118
	do	44	123	50	217	134
	do	49	127	94	270	100
19	S. pestifer and A. rosea	112	284	220	616	144
	do	85	182	100	367	274
	S. pestifer	43	85	49	177	282
	S. pestifer and A. rosea	233	451	471	1,155	120
	do	207	270	104	581	167
	do	290	603	414	1,307	121
26	do	35	95	14	144	40
	do	59	141	3	203	66
	do	198	445	9	652	100
	do	241	423	46	710	298
	do	39	89	6	134	15
21	do	37	86	12	135	96
	do	15	46	6	67	151
23	do	3	6	12	21	445
	do	3	4	2	9	6
26	do	35	77	11	123	88
Oct. 25	do	0	0	0	0	0
	do	35	31	2	68	6
	Chrysothamnus	116	104	1	221	15

TABLE 39.—*Insects collected on host plants of Eutettix tenellus in the Twin Falls district, illustrating the predominance of E. tenellus in 1927*—Continued

Date	Host	E. tenellus				Others species
		Males	Females	Nymphs	Total	
	S. pestifer	129	269	58	456	136
	do	122	195	46	363	42
	do	124	225	171	520	79
	do	18	85	3	106	20
	do	77	189	202	468	63
	do	39	102	57	198	154
	do	1	0	0	1	1
	do	4	8	1	13	324
	do	71	208	29	308	4
Sept. 21	do	115	207	95	417	142
	do	168	525	150	843	48
	do	75	201	57	333	52
	do	132	269	261	662	147
	do	153	297	48	498	40
	do	104	248	39	391	267
	do	106	302	364	772	114
	do	42	91	2	135	38
	do	11	23	9	43	37
	do	25	80	23	128	41
	do	3	2	1	6	75
	do	1	2	0	3	7
22	do	2	6	4	12	29
	do	1	3	0	4	30
	do	33	128	17	178	38
18	do	5	7	0	12	18
9	do	23	60	12	95	42
	do	71	250	48	369	102
	do	319	696	127	1,142	99
	do	10	37	18	65	39
	do	23	84	21	128	29
23	do	157	294	28	479	46
	do	38	100	39	177	289
	do	192	385	104	681	41
	do	94	245	62	401	27
	do	122	247	43	412	50
	do	67	147	2	216	446
	do	0	0	0	0	5
	do	12	10	0	22	19
	do	1	2	0	3	4
	do	1	6	0	7	6
	do	49	18	3	70	4
Oct. 25	do	2	0	0	2	1
	do	7	10	0	17	1
	do	5	0	0	5	1
	do	0	0	0	0	0
	do	3	2	0	5	2
	do	2	2	0	4	8

USEFULNESS OF THE DATA TO THE BEET-SUGAR INDUSTRY

Sugar companies in the seriously affected parts of the intermountain region, and particularly in southern Utah and the central Snake River Plain, are faced with no alternative but that of moving factories if a permanent solution of their problem can not be found. Intermittent operation, if guided by successful forecasting, will do much to alleviate the gravity of the situation, but one-third the present mill capacity will suffice in those areas if intermittent operation is all that can be hoped for.

The exploration for suitable sugar-beet territory, as far as the possible presence of *E. tenellus* is concerned, can be materially assisted by the use of these data. The Bitterroot Valley is a case in point. The sugar company which has recently announced its intention of building a factory there used the data of this study when the question of possible outbreaks of *tenellus* was considered. It is recognized that the district lies in a border-line zone, but the data indicate

that *E. tenellus*, while no doubt to be found, will not develop populations of economic importance.

The area from Las Vegas, N. Mex., to Raton, N. Mex., is well worth investigating, since the indications are that this area should be reasonably free from damage.[8] The damage in 1927 at Las Vegas probably represents a maximum, and Raton with its more favorable mean minima should be even less affected.

Three Texas areas (Fort McKavett, Amarillo, and Midland) might also be investigated with profit.

The more northern States east of the Rockies are indicated as safe as far as leaf-hopper outbreaks are concerned.

MIGRATION AND THE LIMITS OF DISTRIBUTION

It is obvious that in the case of a migratory insect the limits of distribution may not coincide with the economic limits suggested in this bulletin. The discovery of the curly-top disease in South Dakota (*29*), of the disease and the insect in Montana east of the Continental Divide (*7*), of the insect and disease 140 miles north of the Canadian boundary (*16*), and of tomato yellows (due to the same virus as curly top) in Muscatine, Iowa, are probably all cases of the insect migrating out of its normal range into areas where it can not survive. The extreme case is found in the record of the insect in Florida (*17*). Economic loss in such areas on the fringes of the insect's range is extremely unlikely.

There is a possibility of highly specialized local environments maintaining the insect in districts which climatically are quite unsuited for it, but such areas are likely to be small and the populations of *E. tenellus* noneconomic.

Work is now under way on surveys in Texas, Iowa, and New Mexico. Surveys in Mexico have been under way for some time, and in the near future the distribution of the insect should be a matter of complete record.

THE ENVIRONMENTAL COMPLEX, ITS MEASUREMENT AND SIGNIFICANCE TO ENTOMOLOGY

In a recent contribution to quantitative biology Chapman (*9*) pointed out the desirability of reducing the factors of environmental resistance to mathematical terms. For purposes of demonstration Chapman used the simple case of *Tribolium confusum* Duv. in an environment of wheat flour. Even for a relatively stable environment such as this is, Chapman states that "at first the total value of environmental resistance is unassignable to definite factors."

In the case of a field environment, however, the analysis of the environment in terms of isolated factors is of doubtful value since any one factor must be considered in relation to the rest of the environmental complex. It is true that single factors can be modified experimentally, leaving the rest of the environment unchanged; however, except for a limited group of insects, the rest of the environment does not bear the remotest resemblance to that encountered in the field. This perhaps is a matter of technic, the development of experimental laboratories to the point where they are capable of

[8] It should be recognized that this study does not cover any phase other than that concerning the insects; economic or agronomic factors would no doubt be relevant but beyond the scope of this bulletin.

providing a reasonably accurate duplication of, at least, the physical factors of the environment. Shelford (*31*) records progress along this line, and a definite recognition of the problem involved is contained in Forbes's introduction to Shelford's paper. There is a development, however, which should run parallel (though perhaps at a faster rate) to the above-mentioned one and which is in harmony with the fundamental concept of Chapman's work in that it depends for its data on accurate quantitative measurements of factors. This is the use of the concept of the environmental complex as a working basis. It may not be possible to define the environmental complex except in terms of individual factors which are themselves not reducible to a common denominator. This does not necessarily preclude their use or depreciate their usefulness in evaluating the environment. As a matter of fact, the difficulty of finding a true common denominator involves the danger of mathematical treatment of data which are themselves not mathematically precise.

The study of *Eutettix tenellus* can be used to show how the concept of the environmental complex permits the evaluation of the action of the environment on an insect's population and behavior. In this particular instance there are perhaps four phases of significance: (1) The winter and its resistance to the insect's hibernation; (2) the spring complex, governing the development of the first generation, the condition of the host plants, and subsequent migration of the insect; (3) the host-plant succession on the desert during the summer; and (4) the fall complex governing the size of the third generation and consequently the population entering hibernation.

Temperature data for the winter months (Tables 2 and 3) and the discussion under "Prediction of outbreaks" show under what conditions of temperature the complex offers high and low winter resistances. That these resistances are associated with factors other than a simple or direct temperature reaction has already been suggested, but whatever the explanation may be, certain conditions of temperature seem definitely associated with winter resistance.

Preparation for spring activity (ovary development) is evidently stimulated by a combination of temperature and solar radiation, but the amounts necessary are so small as to make it extremely unlikely that much, if any, variation between seasons will be encountered. After ovary development has been completed, the environmental complex operates along many lines, some parallel, some converging. Table 4 shows data on the temperature factor while Tables 6 and 7 include these data along with other measurements on the environment. Table 4 illustrates the temperature range through the local environment, but a comparison of the detailed data of Table 5 shows that the ratio of standard-shade temperatures to soil-surface temperatures is not a constant, so other factors must enter in. These are probably (1) wind, moving the warmed air rapidly from the surface of the soil; (2) precipitation, cooling the soil surface through expenditure of heat of evaporation; and (3) cloudy weather interfering with solar radiation and reducing absorption of heat by the earth's surface. As far as the area contiguous to the instrument is concerned the data of Table 4 actually represent a summary of temperature as it is acted upon by these and possibly other factors, which illustrates the point that for purposes of analysis of the environmental complex the use of factors which are themselves summaries offers the best approach.

In considering the question of food supply these summarized factors are of great importance, in fact are the only ones available. The growth of specific wild host plants is a summary of all the factors affecting the plant's development, but it should be remembered that these factors may not concern the insect's development in the same degree. Cell-sap concentration is a summarized factor capable of accurate measurement. Soil-moisture content is also a summary of at least three external factors—precipitation, temperature, and evaporation—the last named being itself a summary of air movement, precipitation, temperature, and relative humidity. A large number of factors are thus expressible in terms of those whose measurements are reported in this bulletin. Quantitative sweeping has been the method whereby the populations of *E. tenellus* in the environment have been measured. This incidentally has afforded an opportunity to measure the factors of competition and association of species in the insect community.

THE APPLICATION OF DATA ON THE ENVIRONMENTAL COMPLEX TO PROBLEMS IN ECONOMIC ENTOMOLOGY

Any season for which detailed environmental measurements exist coincident with measurements of the insect's population and behavior can be used as a type complex with which other complexes can be compared. This will of course be limited by the scope and detail of the data available for any one season. Furthermore, since the effect of the environmental complex for any one season can only be evaluated through a consideration of the effects of complexes of previous seasons, the desirability of continued observations in the same locality is obvious.

Prior to 1919 no records are available concerning insect migration into the Twin Falls district, but records from 1919 to 1928, inclusive, are available. These became more accurate as workers in the beet-sugar industry became more familiar with the problem. The type winter complexes are discussed in detail under "Prediction of outbreaks"; it is sufficient to say here that there is a fairly clear though empirical relationship to be found between certain winters and leafhopper outbreaks during the succeeding year. The only environmental data available in this connection up to the winter of 1925–26 are those from Weather Bureau records. Data on the spring complex are available for the years 1926, 1927, and 1928, in greatest detail for 1927 and 1928. These three seasons illustrate the use of the concept excellently. The season of 1926, a most disastrous year from the standpoint of outbreaks of *E. tenellus*, was characterized by an extremely mild winter preceding a very early opening up of spring, high temperatures, wind, and subnormal precipitation. Associated with this combination was the earliest first generation and migration of the leaf hopper on record for this area, also the disruption of the host-plant succession during the summer and the practical elimination of the desert as a breeding ground for the insect except in favored places. The season of 1927 differed materially as far as temperature, winds, and precipitation were concerned. The host-plant succession was very favorable for the insect. The factor of competition was suggested by the presence of enormous numbers of *Plutella maculipennis*, the only occurrence of this insect in the four seasons of observation. The behavior of the insect in this season

forced the consideration of migration as being normally associated with the development and behavior of the spring generation, but no conclusions can be reached on this point until the evidence of succeeding complexes is available. The development of the spring brood should be a subject amenable to measurement on the basis, for example, of accumulated temperatures, so that if the migration is only a matter of the development of the spring brood, temperature accumulations for the period prior to the migrations of 1926 and 1927 should be approximately equal. Reference to Table 4 will show that such is not the case.

The relation of migration to the complex was even more obscure in 1928. Table 7 lists temperature and other external factors in comparing 1927 with 1928, while Table 40 compares soil moisture and other data for one of the desert observation stations. There is nothing in Table 7 to suggest the movement of *E. tenellus* into the beet fields which was first observed on May 6, 1928. The data in Table 40 are more suggestive, since they indicate that certain host-plant conditions were undoubtedly unfavorable. The host plants in 1928 were a month ahead of those of 1927. A period of cool weather in April reduced the lead somewhat, but by comparing conditions the second week in May it is seen that the host plants of 1928 were fully a month ahead of those of 1927. Not only was this true, but in many places at this time in 1928 *Sisymbrium altissimum* was almost eliminated and *Sophia sophia* was suffering from drought. The uneven condition of the desert vegetation was most pronounced and extremely local in character. The steady dribbling movement of the insect into the beet fields associated with such a condition is of possible value in interpreting migration stimuli. As a matter of fact, difficult as is the interpretation of the migration of *E. tenellus*, the concept of the environmental complex has been most useful in approaching the problem. Carsner (*4*) uses essentially this concept in questioning the factor of periodicity.

TABLE 40.—*Phytometric and other data of the spring of 1927 compared with those of the spring of 1928, Twin Falls, Idaho*

Spring of 1927						Spring of 1928					
Date	Phytometric data	Depression of cell-sap freezing point		Soil moisture		Date	Phytometric data	Depression of cell-sap freezing point		Soil moisture	
		S. altissimum	S. sophia	0 to 6 inches	6 to 12 inches			S. altissimum	S. sophia	0 to 6 inches	6 to 12 inches
		°C.	°C.	*Per cent*	*Per cent*			°C.	°C.	*Per cent*	*Per cent*
Apr. 23	Plants very small, one-fourth to one-half inch high.	----------	----------	15.10	17.56	Mar. 23	Sisymbrium altissimum one-half to 1 inch rosettes; rare. Sophia sophia 1 to 2 inches high.	----------	----------	12.45	14.17
May 12	Sophia sophia 1 to 4 inches high----	1.11	1.27	18.05	19.49	Apr. 9	Sisymbrium altissimum apparently not changed. Sophia sophia 1 to 4 inches high.	----------	1.63	13.06	16.88
						25	Sisymbrium altissimum 1 to 3 inch rosettes. Sophia sophia 2 to 5 inches high.	----------	----------	13.15	17.47
27	Very little advance; plants too low for quantitative sweeping.	1.44	1.36	14.35	15.03	May 9	Sisymbrium altissimum dying; short, premature flower stalk. Sophia sophia 6 inches high. In dry places thin and in premature flower.	----------	1.84	5.70	9.55
						17	----------	----------	----------	7.00	8.61
June 11	All mustards rank and in full bloom.	1.60	1.45	12.41	10.27						

The diagrams of the desert observation stations (fig. 12) are also a valuable record for comparative purposes. By the third week in May, 1928, it was evident that host-plant areas were materially changed. Not a single specimen of *Sophia filipes* could be found at the Castleford station. *S. altissimum* was very much reduced, while *S. sophia* was normal over only a fraction of the previous year's area. Since insect populations over a gross area are the product of the populations per unit area and the number of unit areas available, some such method of comparing host-plant areas will materially assist in the evaluation of this factor in the complex.

The data in Table 40 were of great practical value in the spring of 1928. A number of farmers who had planted small acreages of beets with the expectancy of possibly planting other crops were faced with the necessity of making a decision as to thinning before the migration of *E. tenellus* took place. The data, illustrating as they did the premature aging of the desert host plants, the necessity for very heavy precipitation if the desert soil moisture was to be brought to a favorable point, and the increase of accumulated temperatures over those of 1927, were made available. This information, with the added fact that leaf-hopper populations were very large, did much to prevent cash outlays on beet acreage which was foredoomed to failure.

SUMMARY AND CONCLUSIONS

Eutettix tenellus Baker is a serious pest of sugar beets and other truck crops in the intermountain region of the Western States. Since the problem presented by the insect's activities can not be met by the standard entomological methods, it has been approached from the standpoint of quantitative ecology. A large permanent breeding ground in southern Idaho has been the locale of the study.

The physical factors measured and considered are solar radiation, humidity, temperature, evaporation, wind movement, and precipitation. Soil moisture is recognized as an important summary of factors.

Intraenvironmental differences in temperature are shown to be a feature of the environment. In winter the soil-surface maxima often rise to points permitting activity for the insect. Increments of such maxima permit the insect to develop its eggs during the winter. Minima during the winter on the soil surface did not reach lethal temperatures as determined by laboratory experiments. The soil surface is highly protected against extremes of temperature during the winter. The greatest range of temperature encountered occurs at the 6-inch level above ground, so that during periods of low winter air temperatures very great differences exist in a very short vertical range.

During the summer season the heat absorption by the soil and the gradual establishment of optimum temperatures through the vertical range of the environment are significant. The disestablishment of the optima in the fall governs in large measure the size of the third brood of *E. tenellus*. The optimum environment from the standpoint of physical factors appears to be found in a stand of Russian thistle (*Salsola pestifer*) in sparse growth. This optimum is only approached in a beet field if the stand is poor or the beets are suffering from curly top.

Data are presented showing the effects of constant, alternating, and fluctuating temperatures. Constant-temperature studies indicate the temperature range within which the rate-of-development curve is a straight line, but the data are difficult of interpretation in terms of actual environments encountered. Climate-simulation experiments offer the best approach to the problem of evaluating temperature effects.

The effects of light, humidity, and wind movement are discussed. A relationship seems to exist between intensity of light and phototropism; and light appears to have some effect on the preoviposition period of the insect. Humidities approaching saturation are fatal if maintained for a long time, but such humidities have never been encountered in the breeding ground studied. The insect is unaffected by wind, unless disturbed.

Relations between insect and host plants were studied as sources of information on cause of migration, factors affecting abundance, and the possible cyclic nature of abundance. Introduced hosts on abandoned lands are responsible for the present economic situation.

Cell-sap concentration and maturity are two factors considered as measures of a plant's reaction to the environmental complex and the insect's reaction to the plant. Between plant species of the same xerophytic habit and growth form, cell-sap concentration appears to be a factor of importance. Both factors are important phytometrically in comparing one season with another.

Perennial host plants probably maintained the insect before the advent of introduced hosts. They are unimportant from the standpoint of economic populations but serve on occasion as important stages in the host-plant succession. Greasewood (*Sarcobatus vermiculatus* Torr.) is a favorable host from the standpoint of the measured factors, but balance has probably been struck between *E. tenellus* and its competitors so that predominance of *E. tenellus* is prevented on this host.

A succession of host plants is normally provided, including the mustards (*Sophia sophia*, *S. filipes*, and *Sisymbrium altissimum*), *Atriplex rosea*, and *Salsola pestifer*, together with occasional hosts such as *Solanum triflorum*. *S. pestifer* is the most important late summer and fall host. The presence or absence of this plant determines in large measure the distribution and size of the populations of *E. tenellus* entering hibernation. The mustards are important spring hosts, since it is from these that the migrations take place in the area studied. Quantitative data from desert observation stations in 1926 and 1927 indicate relationships between host plants (maturity and cell-sap concentration), soil moisture, and populations of *E. tenellus*. Migration in the area studied is largely governed by host-plant relationships. It is probable that normally the insect does not migrate from *S. pestifer*. A migratory instinct must be considered but is difficult to separate from considerations of host-plant conditions. Competition is suggested as a possible factor in migration; it probably acts by conditioning the suitability of the host plants.

The insect community at any given time presents a summarized effect of a large number of factors; the insect community is conceived of as an entity. Specific predominance is evidence of a favorable environment for the species. Changes in predominance correlated with measurements of the environmental factors will assist materially

in evaluating effects of climate and weather. The species of mustard furnish opportunity for predominance of leaf-eating forms early in the spring. Later *E. tenellus*, having capacity to use environments beyond the limits of tolerance of other species, succeeds to a predominance which often amounts to numbers greater than all other species combined.

E. tenellus does not undergo true hibernation. Hibernation cages must contain suitable food or the insect will perish from starvation during the winter. Recovery from hibernation cages following the winter of 1927–28 was much greater than it was following the winter of 1926–27. This difference in recovery can not be explained on the basis of either intensity or cumulative effect of low temperatures. The more frequent the occurrence of temperatures below zero Fahrenheit, the greater the reduction in overwintering populations. Late fall food appears to be of some importance. Exposure to contact moisture appears to lessen the insect's resistance.

Prediction of leaf-hopper outbreaks has been attempted for the Twin Falls district, contiguous to permanent breeding grounds. The beet-growing area from Declo, Idaho, to Buhl, Idaho, is such an area. Yield records indicate the years of very severe damage, those of moderate to severe damage, and those of little damage. Individual-grower records indicate that certain growers rarely sustain cash losses but that even in the years of highest average yields some losses are sustained.

Economic factors determine what is the lowest average yield which must be obtained if the beet crop is to maintain itself against competition with other crops. This minimum average yield varies considerably in the districts included in the area under consideration. A basis for prediction as to probable population and migration of the insect was arrived at by analysis of the insect's desert environment and a study of the past records. The types of season with their typical environmental complexes associated with years of heavy or light leaf-hopper injury have been recognized. Records for all the winter seasons from that of 1918–19 to that of 1927–28, inclusive, are presented in chart form and discussed. The predictions issued in 1927 and 1928 contained a presentation of summarized data, so that farmers in the area had the information available and could make their own decisions.

Prior to 1927 the highest acreages had nearly always been contracted for in the years of greatest damage. The acreages following a severe outbreak had always been much reduced. The prediction service has already done much to reverse these trends in the area under observation. Prediction of time of migration would be of material assistance to growers of other truck crops affected by the curly-top virus.

The probable economic distribution of *E. tenellus* has been worked out on the basis of a study of the insect in Idaho through an area where conditions for the insect vary from optimum to limiting.

The concept of the environmental complex offers a method of approach to problems in entomology. The method involves quantitative measurements of environmental factors, physical and biotic, and the evaluation of the effects of a complex through comparison with previous complexes for which data are available.

The optimum environment for *Eutettix tenellus* Baker with respect to physical factors is found in a sparsely growing stand of Russian thistle (*Salsola pestifer*).

The seasonal development of the host plants governs the migration of the insect in southern Idaho.

Host-plant succession throughout the season is essential if a true permanent breeding ground is to be maintained.

Severe winters are followed by reduced populations of *E. tenellus* and consequently good yields of sugar beets in southern Idaho.

The insect has probably reached the limits of its economic distribution, although occasional occurrences of the insect or of curly-top virus may be expected in areas far removed from its normal range.

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